UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1335

Washington, D. C. ▼ September, 1925

COMMERCIAL DEHYDRATION OF FRUITS AND VEGETABLES

By

P. F. NICHOLS, RAY POWERS, and C. R. GROSS, Laboratory of Fruit and Vegetable Chemistry
and W. A. NOEL, Office of Development Work
Bureau of Chemistry

CONTENTS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1925

UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1335

Washington, D. C. ▼ September, 1925

COMMERCIAL DEHYDRATION OF FRUITS AND VEGETABLES

By P. F. Nichols, *Investigator in Commercial Dehydration*, Ray Powers, *Junior Chemist*, and C. R. Gross, *Junior Chemist, Laboratory of Fruit and Vegetable Chemistry*, and W. A. Noel, *Associate Development Engineer, Office of Development Work, Bureau of Chemistry*

CONTENTS

PRESERVATION BY DEHYDRATION

Spoilage of raw food is due principally to the growth of molds and bacteria. This growth does not occur when the soluble solids are sufficiently concentrated by the reduction, by drying or by other means, of the water present in foods. Even if they are not killed, the molds and bacteria remain dormant and harmless in the absence of a suitable medium for their growth. Changes in composition, flavor, and appearance, however, may also be brought about by the action of the enzymes present in practically all foodstuffs. As these ferments are not always destroyed by the treatment which stops mold and bacterial action, they must be considered in working out methods of dehydration.

Note.—This bulletin is intended primarily for the use of those who either have decided to enter or are already in the dehydration industry. The information here given will enable beginners to proceed with a fair assurance of being able to prepare satisfactory dehydrated fruits and vegetables and it will assist those now engaged in the work to improve their methods.

The investigation here reported was undertaken to determine certain physical principles and their adaptation to dehydration problems in general. The project was discontinued before it was possible to consider the modifications necessary for the different varieties of fruits and vegetables. Factors leading to the deterioration of dehydrated products and the relation which the condition and the variety of fruits and vegetables may bear to this deterioration, important phases of the problem not here considered, are being investigated in the Bureau of Plant Industry.

38850°—25†—Bull. 1335——1

The outstanding advantage of drying as a method of preserving foods is that the weight and bulk of the products are greatly reduced, thus making possible economy in storage and transportation. This saving will become more significant as the need for food conservation in the United States increases. The production cost of dehydration compares favorably with that of canning, and no cases of food poisoning, such as botulism, have been traced to dried foods. Dried fruits and vegetables are as convenient for use in the home as the fresh products. They need no peeling or other preliminary treatment, and soaking and cooking can usually be combined. Only the quantity required need be used at one time; the rest will keep in good condition.

Two objections to the use of dehydrated foods still exist. They require soaking and cooking and they do not always reach the consumer in good condition. There is no evidence at present that the first objection can be overcome. The second objection, however, will undoubtedly disappear as familiarity with dried foods increases the demand for them.

DEHYDRATION INDUSTRY

"Dried," "sun-dried," "evaporated," and "dehydrated" are the terms most commonly used to describe dried products. "Dried" indicates drying by any means; "sun-dried" indicates drying without artificial heat; and "evaporated" implies the use of artificial heat. To-day the term "evaporated" refers more particularly to the use of artificial heat in driers depending for their air circulation on natural draft, while "dehydrated" implies mechanical circulation of artificial heat.

The commercial dehydration of fruits has reached a more advanced stage of development than has the commercial dehydration of vegetables, owing largely to the fact that the public is familiar with sun-dried and evaporated fruits, whereas it knows comparatively little about dried vegetables. Fruit drying in the United States is confined almost entirely to California, the Pacific Northwest, and western New York (Table 1). The prunes in the Pacific Northwest and the apples were dried almost exclusively by evaporation, but practically all the rest of the fruit listed in Table 1 was sun dried. The dehydration of prunes and other fruits is becoming more extensive (Table 2).

During the World War 8,905,158 pounds of dehydrated vegetables, divided as follows, were shipped to the United States Army overseas: Potatoes, 6,437,430 pounds; onions, 336,780 pounds; carrots, 214,724 pounds; turnips, 56,224 pounds; and soup mixture, 1,860,000 pounds.

Table 3 shows the extent of the dried-vegetable industry in this country in 1919. All the vegetables were either dehydrated or evaporated.

DEHYDRATION PLANT

To be successful a dehydration plant must be built where fresh materials are plentiful and reasonable in price. A diversity of products makes possible an operating season long enough to keep the overhead expenses down to the minimum. The products dried, however, should be limited to those for which a ready market exists.

TABLE 1.—*Quantity and value of dried fruits in the United States, 1919* [1]

Fruit	Quantity	Value	Fruit	Quantity	Value
	Pounds			*Pounds*	
Apples	46, 623, 599	$6, 772, 100	Peaches	73, 379, 193	$12, 109, 624
Arkansas	6, 720, 070	805, 157	California	73, 268, 010	12, 074, 246
California	15, 477, 039	2, 630, 300	All other States	111, 183	35, 378
Illinois	274, 354	33, 051	Prunes	136, 377, 066	18, 253, 691
New York	13, 524, 019	2, 234, 128	California	114, 324, 446	15, 211, 293
Oregon	1, 577, 441	191, 490	Oregon	19, 930, 935	2, 785, 373
Virginia	1, 274, 125	122, 425	All other States	2, 121, 685	257, 025
Washington	4, 044, 090	466, 214	Raisins	293, 300, 581	35, 544, 262
West Virginia	203, 000	34, 821	California	293, 300, 581	35, 544, 262
All other States	3, 529, 461	254, 514	All other fruits	37, 852, 258	6, 384, 934
Apricots	24, 192, 628	6, 034, 697	California	33, 235, 543	5, 659, 138
California	23, 944, 612	5, 994, 309	Oregon	3, 177, 585	436, 935
All other States	248, 016	40, 388	All other States	1, 439, 130	288, 861

[1] Fourteenth Census of the United States (1920), vol. 10, p. 79.

TABLE 2.—*Quantity of fruit dehydrated in California in 1921, 1922, and 1923*

Product and season	Total dried [1]	Dehydrated [2]	Proportion dehydrated	Annual increase in proportion dehydrated
	Tons	*Tons*	*Per cent*	*Per cent*
Apples:				
1921	7, 000	620	8. 9	
1922	10, 500	1, 333	12. 7	+42. 7
1923	9, 500	1, 618	17. 0	+33. 9
Apricots:				
1921	12, 000	60	. 5	
1922	15, 500	194	1. 3	+160. 0
1923	25, 000	52	. 2	−84. 6
Grapes:				
1921	138, 500	220	. 2	
1922	235, 000	3, 238	1. 4	+600. 0
1923	190, 000	3, 358	1. 8	+28. 6
Peaches:				
1921	21, 000	13	. 1	
1922	28, 000	362	1. 3	+1, 200. 0
1923	26, 000	67	. 3	−76. 9
Pears:				
1921	1, 200	20	1. 7	
1922	5, 000	65	1. 3	−23. 5
1923	1, 500	55	3. 7	+184. 6
Prunes:				
1921	100, 000	2, 946	2. 9	
1922	132, 000	13, 356	10. 1	+248. 3
1923	110, 000	16, 810	15. 3	+51. 5

[1] California Fruit News (Mar. 8, 1924), vol. 69, no. 1861.
[2] Christie, A. W. California dehydration statistics for 1923. *In* Western Canner and Packer (July, 1924), vol. 16, no. 3, pp. 44–45. Figures recalculated, using reduction ratio (fresh to dry) shown in California Fruit News (July 14, 1923), vol. 68, no. 1827, p. 15.

TABLE 3.—*Quantity and value of dried vegetables in the United States, 1919* [1]

Vegetables	Quantity	Value	Vegetables	Quantity	Value
	Pounds			*Pounds*	
Beans	917, 134	$116, 091	Potatoes	7, 253, 230	$1, 840, 399
California	134, 689	8, 097	California	3, 189, 328	838, 521
All other States	782, 445	107, 994	Oregon	774, 087	176, 806
Cabbage	19, 901	13, 684	All other States	3, 289, 815	825, 072
Carrots	432, 959	117, 487	Spinach	40, 989	41, 352
California	312, 207	88, 568	Turnips	19, 396	8, 264
All other States	120, 752	28, 919	Other vegetables [2]	989, 397	271, 917
Celery	17, 587	11, 100	Soup mixture	655, 228	222, 361

[1] Fourteenth Census of the United States (1920), vol. 10, p. 79.
[2] From 500,000 to 1,000,000 pounds of dehydrated sweet corn is produced annually in Pennsylvania and Ohio. This is not included here.

SELECTION OF MATERIAL

The fresh material must be so solid that it can be spread in a whole or divided condition on wire-screen or wooden-slat drying trays. It must also lend itself to mechanical or rapid hand operations during preparation. Finally, the resulting product must be of good quality. The following fruits meet these specifications: Apples, apricots, cherries, cranberries, grapes, loganberries, peaches, pears, prunes, and raspberries. The following vegetables meet them: Beans (string), cabbage, carrots, celery, corn (sweet), horseradish, onions, parsnips, potatoes, pumpkin and squash, spinach, and turnips. Cabbage, carrots, celery, parsnips, potatoes, and turnips are important principally as soup-mixture ingredients.

Dehydration does not improve the quality of fresh fruits or vegetables, nor does it satisfactorily utilize unsound foods. At best the process can only conserve the original constituents of the foods, minus replaceable water. Not only does the condition of the fresh material affect the quality of the product, but the waste in sorting and trimming, together with the labor involved in preparation, affects the cost of the prepared material. One of the future economic benefits of dehydration probably lies in the more complete utilization of fresh and sound cull or second-grade fruits and vegetables, so classed because of their size or shape.

As a general rule, fruits and vegetables are most suitable for dehydration when the flavors are most satisfactory and the texture remains tender and succulent but firm. Fruits which are fully ripe but firm are preferable. Vegetables with color and texture suitable for table use are desirable. Dehydration kills the living tissues and prevents further ripening of the product.

PREPARATION OF MATERIAL

Careful handling reduces labor and waste. Bruised tissue is especially susceptible to discoloration and decay. Individual pieces prepared from good stock are also more uniform and attractive than those from heavily trimmed stock.

WASHING

Raw materials should be as carefully washed and cleaned for dehydration as for table use. Much of the washing machinery used in canning is suitable for dehydration. A rotary cylindrical washer equipped with a water-spraying system is very satisfactory for washing many types of products. Soft or easily broken fruits and vegetables may be washed by passing the trayed material on an endless belt between several sprays of cold water.

GRADING FOR SIZE

The segregation of fresh fruits and vegetables according to size facilitates both the preparatory handling and the drying.

One type of grader consists of a perforated metal plate, 3 by 10 feet or larger. The perforations are in sections of varying size, and the plate is inclined and mechanically agitated in order to insure an even "flow" of the material in one direction. The product is separated according to size by being passed through the perfora-

tions. Perforated plates are also used in stacks. Several plates, each stamped with holes of uniform size, the holes varying in size with each plate, are set one above the other, with 6 or more inches between plates. They are arranged so that the holes are progressively smaller from top to bottom.

An "approximate-weight" grader may consist of baskets carried on an endless chain. Traps at intervals along the course of the chain are controlled by counterweights of fruits, which represent the approximate weight of the desired product in that size. As the basket carrying the product reaches a trap that is counterbalanced by a lighter weight the trap operates to discharge the product.

Another grader sorts out easily rolling materials according to diameter. As a mechanically-driven cable rolls the materials along an opening that increases in width the product falls through and is collected according to its size.

A grader based on the same principle passes the product down a chute, the floor of which consists of rollers placed crosswise and at increasingly greater distances apart. As the product rolls along the chute it is separated in progression according to size.

PEELING

Manufacturers show a growing tendency to remove the skin from all fruits and vegetables before drying. Because of custom or the type of skin, some kinds, notably prunes and apricots, however, are never peeled.

Peeling may be done by hand or by specially designed machines. Many types of knives, with straight, curved, or guarded blades, and hand-operated cutting machines are obtainable for peeling, trimming, coring, and otherwise preparing the material to be dried. Machines for peeling and coring apples in one operation are available.

Friction or rotary mechanical peelers are particularly well suited for handling tubers. All peelers of this type depend upon the rasping effect of rough surfaces of cement, corundum, etc., forming some part of the lining of the peeler, when the product is rotated rapidly within the cylinder by a moving bottom. The material is introduced at the top and discharged by a side door. These machines are usually equipped with water sprays, which wash off the dirt and the particles of skin removed by the peeler.

Two types of peelers are based on the reaction of lye with certain tissues under the skins of fruits. In one type the fruit is passed through sprays of hot lye solution; in the other it is immersed in the lye solution. In the second type (fig. 1) the fruit is placed in a perforated rotating metal cylinder, part of which is submerged in a hot lye bath. By means of a worm or other device the product is forced through the cylinder and delivered to a corrugated metal cylinder rotating on an incline, where cold water sprays remove the loosened skin and wash the fruit free of lye. In another system sometimes used (fig. 2) the fruit is placed in a wire basket, which is immersed in a tank containing the hot lye solution. This operation is followed by washing and rubbing the product free from skins.

In the lye-peeling machines provision should be made to keep the lye bath hot, preferably between 190° and 200° F., as its effectiveness is greatly reduced at lower temperatures. The strength of the lye bath is between 1 and 3 per cent, depending on the nature and con-

dition of the material being peeled. The time of immersion should be sufficient to loosen the skin, but not long enough to discolor or injure the material. Usually an immersion of 15 to 45 seconds will bring about the desired results.

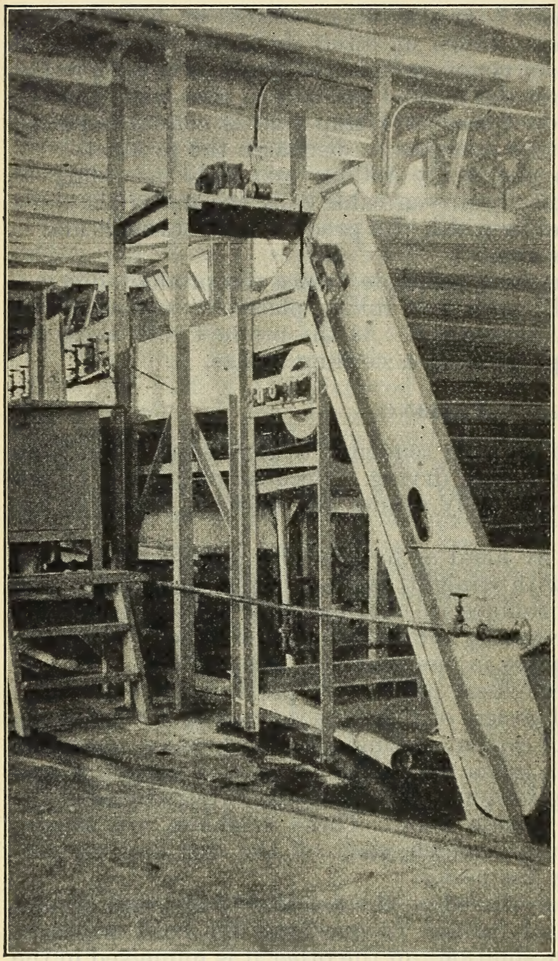

FIG. 1.—Conveyor-belt mechanical lye-spray peeler and washer

TRIMMING

Following the peeling, the fruit or vegetable must be inspected and all remaining skin removed by a special knife.

CHECKING

Lye is used to check the skins of prunes and grapes, so that their drying may be facilitated. Lye-dipping vats or lye-peeling machines of the types described on page 5 are used. The fruit is immersed in the hot lye solution long enough to break the skin by many minute fissures or "checks," but not long enough to loosen it. The concentration and temperature of the lye bath, as well as the duration of treatment, are similar to those for lye-peeling.

SUBDIVIDING

Three considerations affect the choice of the form in which materials are prepared for dehydration: (1) The desire of the consumer for a product in the form to which he has been accustomed, (2) the necessity for the manufacturer to subdivide the product to facilitate drying, and (3) the desire of the manufacturer to make a product of distinctive appearance. Most fruits are sliced, cubed, halved, or left whole. Usually vegetables are sliced, cubed, shredded, or chipped.

The cutting is done by hand or by some one of the numerous machines on the market. Some of the machines consist essentially of

rotating knives or cutting surfaces operated by hand or by power. In others the cutting surfaces are stationary and the product is forced against the blades. One of the most satisfactory types belongs to this class. In the center is a circular surface, having at the circumference a channel about 6 inches wide and 6 inches deep. In the bottom of this channel two gangs of 8 to 12 knives are placed diametrically opposite each other. The material to be sliced is fed upon the middle of the rotating surface, whence a device causes it to be carried outward to the channel, where it is forced over and through the knives by sloping arms.

Special machines for cutting beans are made. By means of a vibrating hopper the beans are fed to a revolving drum with pockets that convey the material to the cutting knives. The cut beans are delivered to a screen where the short ends are sorted out. It is possible to buy machines cutting desired lengths.

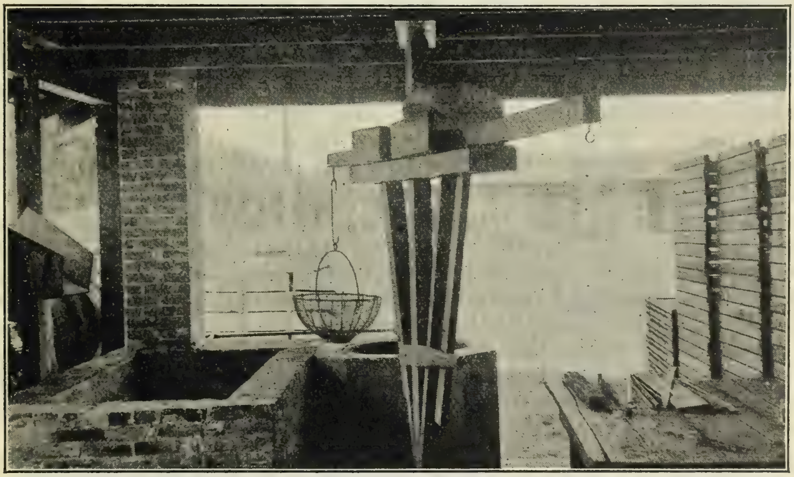

FIG. 2.—Hand-operated lye dipper and washing vat

In the most satisfactory type of cubing machine the slices are cut, carried to a die, and forced through by means of a plunger.

PITTING AND SEEDING

Manufacturers find it desirable to pit or seed stone fruits, as pitted or seeded fruits dry more rapidly and sell more readily than those from which the pits or seeds are not removed.

Satisfactory machines for pitting fresh cherries are on the market, and efforts are being made to develop good machines for other fresh fruits.

The cherry pitter consists of a revolving drum containing numerous pockets, each of which has a hole in the bottom. The cherries are fed into these pockets, which are set in rows at regular intervals. As the drum revolves rows of synchronized plungers force the pits out through the holes in the pockets. Unless it is collected and utilized in some way, much juice is lost.

Machines for seeding raisins and dried prunes have been developed to a satisfactory degree. They consist of a gang of toothed disks much like circular saws, which rotate against a rubber-covered cylinder, revolving in the opposite direction, and force the seeds between the disks. The seeds that remain mixed with the fruit are then automatically separated on a shaker. The fruit is softened by steam or hot-water processing before being passed through the seeders.

TRAYING

After the raw material has been prepared in the desired form, no time should elapse before traying and subsequent treatments preliminary to its being placed in the drier. No definite rule can be given in determining the quantity of material to be placed on a unit area of tray surface. Experience will soon show the operators how much will insure equal pretreatment and even, rapid drying. Many of the larger fruits should be trayed only one layer deep.

Trays should be light but capable of withstanding strain, and they should permit a maximum exposure of the materials. Trays of the type most often seen have a spreading surface formed either of wire screen or wooden slats held firmly in a narrow but rigid wooden or metal frame. Many of the trays now in use have been employed in sun or other drying. If new trays are made, however, the "one-man" tray, about 2½ to 3 feet square, is most convenient.

Galvanized-iron, aluminum, and monel-metal screening have been tried with varying degrees of success. The galvanized-iron screening is the most practical at present, considering initial costs, repairs, and effect upon the material. Aluminum and monel metal have possibilities that merit further study.

Wooden-slat trays can be more cheaply constructed than wire-screen trays, but they have a high rate of upkeep. These trays, however, are not affected by sulphur fumes or fruit acids, for which reason they are preferred for most fruits.

CONVEYING THE TRAYED MATERIAL

The trucks for conveying loaded trays are of two general types. In one type a skeleton frame is provided with cleats, upon which the trays rest. The cleats are from 2 to 4 inches from center to center above one another. These trucks are made of various combinations of wood or angle iron. The other type, which may be called the stack type, has a low floor supported by wheels 3 to 5 inches in diameter. The trays are piled or stacked one above the other, and the desired space between them is maintained by the raised sides of the trays. Various alterations may be made for convenience in handling and loading.

PRETREATMENT

The original method of preparing fruits and vegetables for drying consisted in washing, peeling when desirable, cutting, and traying. By this method most dark-colored materials made fairly presentable dried foods, but light-colored fruits and vegetables did not. The attempt to overcome this difficulty led to the introduction of blanching, or processing, and sulphuring.

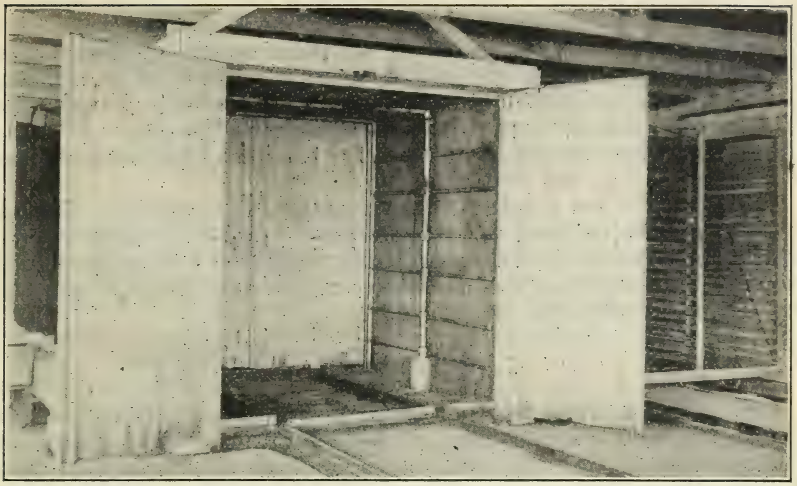

FIG. 3.—Chamber equipped for either steam blanching or sulphuring

BLANCHING OR PROCESSING

The blanching or processing agent is usually steam, hot water, or a hot salt or soda solution, which helps the product to retain its natural color. In the steam treatment the material is subjected to live steam for the required period. In blanching by hot solution the temperature is maintained at 180° F. to the boiling point, depending on the material being treated. As a rule, steam blanching is preferred to blanching in solution, because the loss of soluble constituents of the food is less, a better flavored product results, and the use of steam is ordinarily more convenient.

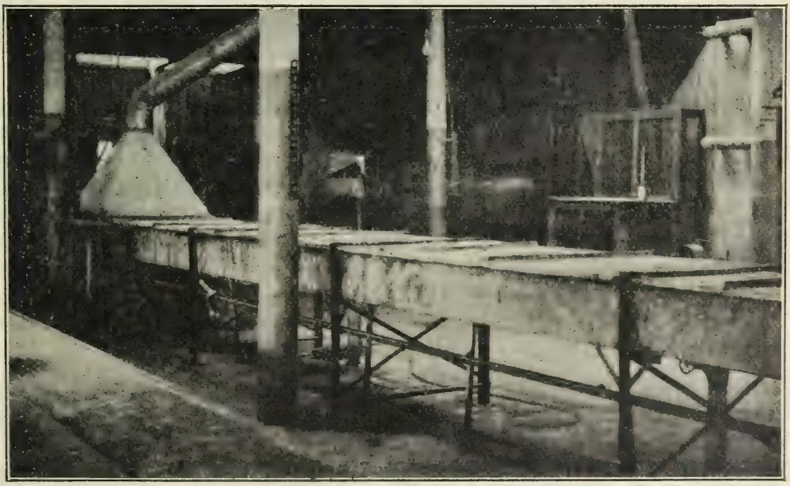

FIG. 4.—Conveyor-type steam blancher

One type of steam chamber consists of a tight room big enough to hold a loaded truck (fig. 3). On at least two opposite walls of the chamber are placed perforated steam pipes about 12 inches apart. In another type (fig. 4) the steam chamber consists of an elongated box similar in construction to the canners' exhaust box, but narrower and longer. An endless chain conveying the loaded trays passes through the box, where steam jets are placed at frequent intervals at the top and at the bottom.

Blanching by hot solution is not practiced extensively. The only type of apparatus used for this purpose consists of a conveyor in which the material is carried through a bath kept hot by steam coils. Some of the product is wasted in passing through the bath, and traying is difficult after this treatment.

SULPHURING

Light-colored fruits are sulphured in order to prevent discoloration during and after drying and to facilitate drying by destroying the capacity of the cell membranes to limit the passage of water through them. It is believed that sulphuring kills and plasmolyzes the cells and makes permeable the semipermeable cell membrane, thus facilitating the diffusion of water from the interior to the surface.

When the general plan of operation makes it desirable, the fruit on trays is "sulphured" in an inclosed chamber, provided with an entrance for the sulphur gas and an exit for a draft (fig. 3). The chamber is usually large enough to hold one or two loaded trucks. Preferably the sulphur is burned in from three to six shallow pans stacked one above the other in zigzag formation. This method gives a large quantity of sulphur dioxide in a comparatively short time. Sometimes a sulphur stove is placed outside the chamber, and the sulphur fumes are carried into the chamber by flues.

Another type of sulphuring apparatus is an elongated box, in which the fumes, conducted to the box from an outside source, act on the fruit as it passes through the box on a wooden slat conveyor. The speed of the conveyor may be regulated to give the proper duration of time for the sulphuring.

Dehydrated fruits are oversulphured much less frequently than sun-dried fruits because a shorter period of exposure is adequate, so that they rarely contain more than 70 milligrams of free sulphur dioxide per kilogram. Occasionally, however, dehydrated fruits have been so heavily sulphured that they have a flavor which many people dislike. Sulphuring, therefore, should always be as light as possible.

DRYING

EQUIPMENT

Driers are of two general types, vacuum and air. Air driers are further classified as natural-draft and forced-draft. Stack and kiln driers belong to the natural-draft type; endless-belt, compartment, and tunnel driers, to the forced-draft type. Almost all types are covered, in part at least, by patents. Many patented special types

combine or modify the characteristics of endless-belt, compartment, or tunnel driers in their design. Aside from several such types which are proving efficient, the ordinary forced-draft driers of the compartment and tunnel types are the most satisfactory for general dehydration. This bulletin deals primarily with driers of this sort; other types are discussed only by way of comparison.

VACUUM DRIERS

Materials can be dried more rapidly and at lower temperatures in vacuum than at atmospheric pressure. Such foods as meats, which are extremely susceptible to damage by heat, therefore, are more safely dried in vacuum. In drying fruits and vegetables vacuum driers can not compete commercially with forced-draft hot-air driers, because of the high cost of construction and operation and the limited capacity of vacuum-drying units.

NATURAL-DRAFT DRIERS

Natural-draft driers depend for their circulation upon the expansion of air when heated and its consequent uplift by adjacent cooler and denser air. Such driers cost less to build than forced-draft driers, but their operation is less efficient and more expensive. It is difficult to obtain satisfactory drying conditions within them, and a long drying period is required. Recirculation is rarely practical with natural draft; consequently heat is wasted unnecessarily in the discharged air. The greater efficiency and economy of forced draft combined with recirculation has been clearly demonstrated by the Bureau of Chemistry and the Oregon Agricultural College. As a result, many operators of Oregon tunnel driers are substituting forced draft and recirculation for the natural draft previously used.

FORCED-DRAFT DRIERS

The essential characteristics of all ordinary forced-draft driers are: (1) A single or multiple-unit drying chamber; (2) an air-heating unit; (3) a power-driven fan; (4) an air duct for conveying heated air from the heater to the drying chamber; and (5) a dampered recirculation duct for returning any part or all of the used air from the drying chamber to the heater.

CONVEYOR-BELT DRIERS

In driers of the conveyor or endless-belt type the material is carried through a drying hood or chamber on one or more moving endless belts made of slats or wire mesh. These driers are used successfully in completing the drying of partially dried raisins and in drying sweet corn. This method is not suited to fruits that stick to the belt or to fruits likely to be injured by dropping from one belt to another when multiple staggered belts are used. Neither are such driers adapted to irregular or discontinuous loading and drying operations. Because of these limitations and their small loading capacity, conveyor-belt driers are less practicable than tunnel and compartment driers for general use.

COMPARTMENT DRIERS

Compartment driers (fig. 5) have a drying chamber divided by partitions into several compartments, each holding one or two stacks of trays. These trays can be handled most conveniently on trucks. Air is carried from the heaters through a main duct, from which portions are diverted to each compartment. Circulation in a vertical direction through the tier necessitates a shifting of the trays during drying, inasmuch as the contents of the trays farthest from the source of the air supply dry more slowly than the material on near-by trays. For this reason circulation of the air across the trays is preferable. The air is discharged from each compartment into a recirculation duct, to be either reheated or discharged from the drier without passing through any other compartments.

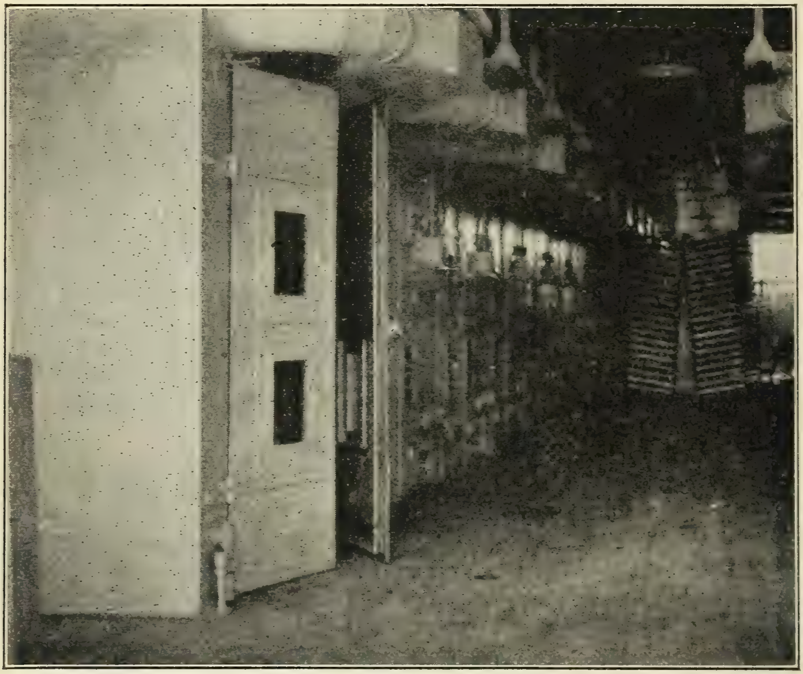

FIG. 5.—Compartment drier

TUNNEL DRIERS

In tunnel driers (fig. 6) the drying is done in a long chamber or tunnel, in which both the materials and the air move horizontally for the most part. A concrete slab floor, hollow-tile walls, and a reinforced-concrete ceiling make a durable and fireproof drier. Many driers, however, have wooden floors and double walls and ceilings of tongue and groove flooring nailed to a skeleton framework of 2 by 4s. Although the dimensions and capacity of the tunnels vary, a typical tunnel is about 40 feet long, 6 feet wide, and 6 feet high, capable of holding a single line of 10 trucks, each truck carrying a double stack of trays 2½ feet square. Handling the trays on trucks is more

economical than conveying them through the tunnel on slides. The trucks and trays should fit snugly in the tunnel, so that all the air will pass between and across the trays.

The loaded trucks are introduced through a door at one end of the tunnel, and the trucks of dried product are removed through a similar door at the other end. Air locks may be built around these doors to conserve heat during loading and unloading. The doors may be in the side wall at each end of the tunnel, with the air ducts connected at the ends, or vice versa. Flexible movement of trucks is facilitated by transfer trucks, turntables, or pivoted truck wheels.

The course of the air through the tunnel is usually opposite to that of the material to be dried, sometimes called the counter-current system of circulation. Some operators advocate circulating the air in the same direction as the material, in what may be called the concurrent system. Tunnels wide enough to hold several parallel lines of trucks have been built. In these the air is usually circulated across from one side to the other. Screens or vanes are sometimes installed

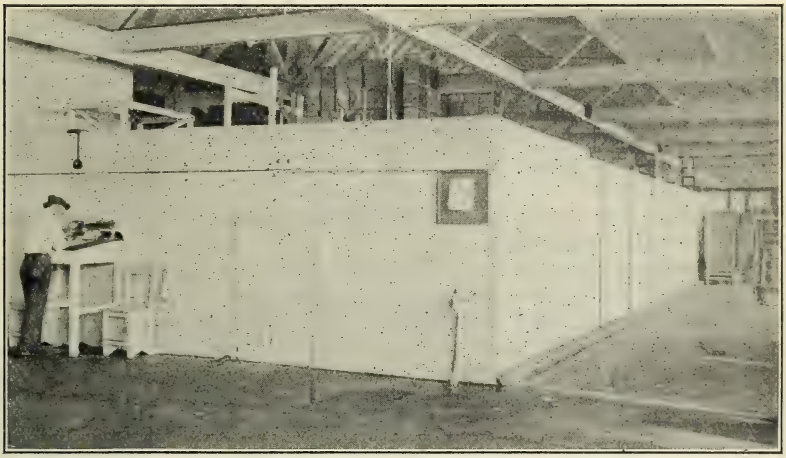

FIG. 6.—Tunnel drier (exterior)

in tunnels at connecting points between air ducts and the drying chamber, so that inequalities in air distribution may be corrected.

HEAT

Heat plays an important part in the evaporation of moisture, first, in supplying the "sensible" heat needed to bring the temperature of the water to the point to which the material is raised during drying, and, next, in furnishing the "latent heat of evaporation," or the heat required to convert water into vapor at the temperature level reached by the drying material. The sum of the sensible heat and the latent heat of evaporation is called the "total heat of evaporation." Heat also facilitates the transmission of water through the cell walls, thereby assisting its passage from the interior to the surface of the material; it increases the vapor pressure of water, thus increasing its tendency to evaporate; and it increases the water-vapor-carrying capacity of the air.

In the United States the unit of heat customarily used is the British thermal unit (B. t. u.), which for practical purposes is defined as the heat required to raise the temperature of a pound of water 1° F.

Heat is most commonly produced through the combustion of oil, coal, wood, or gas. Heating by electricity is seldom practicable because of its greater cost, but where cheap rates prevail it is one of the safest and most efficient, convenient, and easily regulated methods. The average numbers of heat units (B. t. u.) furnished by electricity and various fuels are given in Table 4. With the exception of those for electricity, these average values will vary with the origin and character of the fuel.

TABLE 4.—*Heat units furnished by various fuels and electricity*

Fuel	Heat units furnished	Fuel required to furnish 750,000 B. t. u.
	B. t. u. per pound	*Pounds*
Fuel oil	18,500	40
Coal	12,500	60
Wood (air dried, 10.3 per cent moisture)	7,589	100
Gas	[1] 750	[2] 1,000
Electricity	[3] 3,415	[4] 200

[1] Per cubic foot. [2] Cubic feet. [3] Per kilowatt hour. [4] Kilowatt hours.

Direct heat, direct radiation, and indirect radiation are the types of heat generally employed.

Direct-heating systems have the highest fuel or thermal efficiency. The mixture of fuel gases and air in the combustion chamber passes directly into the air used for drying. This method requires the use of special burners and a fuel, such as distillate or gas, which burns rapidly and completely, without producing soot or noxious fumes. The heater consists simply of a bare open firebox, equipped with one or more burners, an emergency flue to discharge the smoke incidental to lighting, and a main flue, through which the gases of combustion are discharged into the air duct leading to the drying chamber.

Direct-radiation systems also are relatively simple and inexpensive and have a fairly high thermal efficiency. A typical installation consists of a brick combustion chamber with multiple flues, which carry the hot gases of combustion back and forth across an air-heating chamber and out to a stack. The air is circulated over these flues and heated by radiation from them. The flues are made of light cast iron or sheet iron. The air-heating chamber should be constructed of fireproof materials. The efficiency of the installation depends upon proper provision for radiation. This is attained by using flues of such length and diameter that the stack temperatures will be as low as is consistent with adequate draft.

Heating the air by boiler and steam coils or radiators is an indirect-radiation system, as the heat is transferred from the fuel to the air through the intermediate agency of steam. Such a system costs more to install and has a lower thermal efficiency than either of the other two systems. It is principally adapted to large plants oper-

ating over a comparatively long season on a variety of materials where the steam is needed to run auxiliary machinery or to process vegetables.

AIR

Large volumes of air are required to carry to the products the heat needed for evaporation and to carry away the evaporated moisture. Insufficient air circulation is one of the main causes of failure in many dehydrators, and a lack of uniformity in the air flow results in uneven and inefficient drying.

FANS

Propellor-blade fans are not efficient in delivering large volumes of air against the high frictional resistance in commercial driers. Centrifugal or turbine fans are used almost universally. Turbine fans with 48 to 64 or more blades of short radial length are more satisfactory than the standard type centrifugal fan having only six or eight large blades.

The fan may be installed to draw the air from the heaters and blow it through the drying chamber, or it may be placed in the return air duct to exhaust the air from the chamber. An advantage of the first installation is that the air from the heaters is thoroughly mixed before it enters the drying chamber. It has been claimed that exhausting the air from the chamber increases the rate of drying by reducing the pressure, but the difference is imperceptible in practice. Either location for the fan is satisfactory, and the chief consideration in any installation should be convenience.

AIR DUCTS

Close contact between the air and the heaters and between the air and the material is necessary in order efficiently to transfer the heat to the air and from the air to the material and to carry away the moisture. The increased pressures or resistance against which the fan must operate because of such contact is unavoidable and must be provided for, but at other points in the system every effort should be made to reduce friction. To this end air passages should be large, free from constrictions, and as short and straight as possible. Turns in direction should be on curves of such diameter as will allow the air to be diverted with the least friction. The general rule in handling air is that a curved duct should have an inside radius equal to three times its diameter.

MOISTURE IN THE AIR

The water vapor present in air at ordinary pressures is most conveniently expressed in terms of percentage of relative humidity. Relative humidity is the ratio of the weight of water vapor actually present in a space to the weight the same space at the same temperature would hold if it were saturated. Since the weight of water vapor present at saturation for all temperatures here used is known, the actual weight present under different degrees of partial saturation is readily calculated from the relative humidity.

Relative humidity is determined by means of two thermometers, one having its bulb dry and the other having its bulb closely covered

by a silk or muslin gauze kept moist by distilled water. Tap water should not be used because the mineral deposits from it clog the wick, retard evaporation, and produce inaccurate readings. The wick must be kept clean and free from dirt and impurities. The two thermometers are either whirled rapidly in a sling or used as a hygrometer mounted on a panel with the wick dipping in a tube of water and the bulbs exposed to a rapid and direct current of air. The relative humidities corresponding to different wet and dry bulb temperatures are given in Figure 7.

RELATION OF DRYING CONDITIONS TO DRYING RATE AND QUALITY OF PRODUCT

As a general rule, the more rapidly the products have been dried the better their quality, provided that the drying temperatures used have not injured them. Some fruits and vegetables are more susceptible to heat injury than others, but all are injured by even short exposures to high temperatures. The duration of the exposure at any temperature is important, since injury can be caused by prolonged exposure at comparatively moderate temperatures.

The rate of evaporation from a free water surface increases with the temperature and decreases with the increase of relative humidity of the air. The complex cellular structure and chemical nature of fruit and vegetable tissues retard evaporation, so that under no conditions of temperature and humidity does the rate of evaporation from them equal that from a free water surface. When conditions are such that surface evaporation from the tissues exceeds the rate of moisture diffusion to the surface, the surface becomes dry and hard and seals in the moisture. This condition, known as casehardening, is overcome by reducing the temperature of the air or by increasing the humidity. The maximum rate of drying, then, is attained by using the highest temperature which will not injure the product, the humidity being sufficient to prevent casehardening. In general practice, the temperature of the air entering the drying chamber should not exceed 160° to 170° F. The humidity at the air-outlet end of the drier should not greatly exceed 65 per cent. In driers employing recirculation the conditions of temperature and humidity may be largely controlled by varying the recirculation.

The velocities of air flow which produce the most efficient results in the drying chamber depend upon several conditions. In general the rate of drying increases with the velocity of air movement. Low air velocities tend to bring about slow and uneven drying. Exceedingly high velocities may not be used profitably, because a point is reached at which the materials will be blown from the trays or at which the increased speed of drying will not offset the cost of operating a larger fan. Velocities of 600 to 800 feet per minute through the drying chamber are satisfactory in tunnel driers; lower velocities are permissible in compartment driers.

RECIRCULATION

The most practical means of removing moisture from the air, and at the same time conserving heat, is through the steady discharge of a portion of the air leaving the drying chamber. The rest dries efficiently when mixed with fresh air from the outside and reheated.

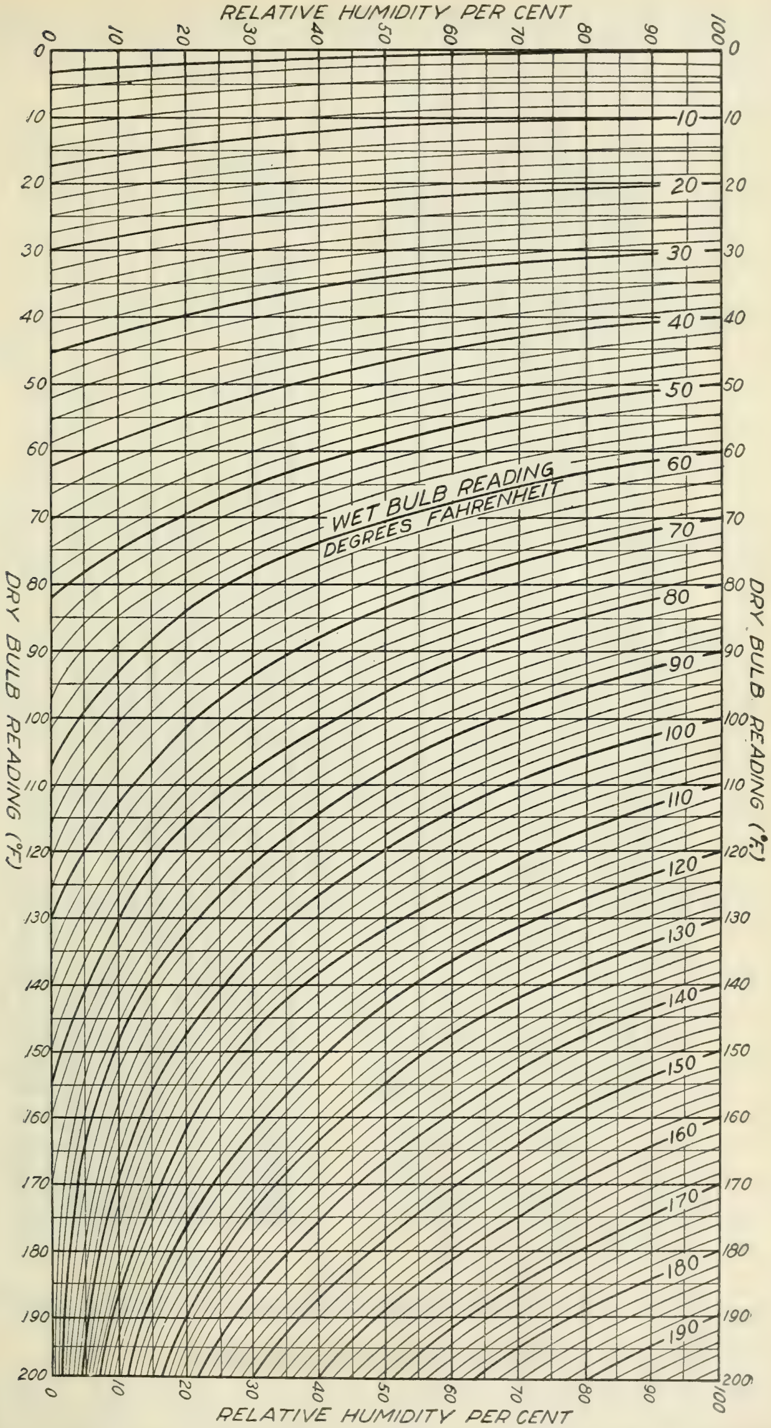

FIG. 7.—Relative humidities corresponding to wet and dry bulb temperatures (based on Psychrometric Tables for Obtaining the Vapor Pressure, Relative Humidity, and Temperature of the Dew-Point (U. S. Dept. Agr., Weather Bureau Bul. 235 (1910), by C. F. Marvin), and on Figure 1, Principles of Drying Lumber at Atmospheric Pressure and Humidity Diagram (U. S. Dept. Agr., Forest Service Bul. 104 (1912), by H. D. Tiemann)

38850°—25†—Bull. 1335——3

All forced-draft driers, therefore, should be provided with recirculation ducts connecting the air-outlet end of the drying chamber with the heaters and with dampers controlling the air discharged, recirculated, and drawn from the outside.

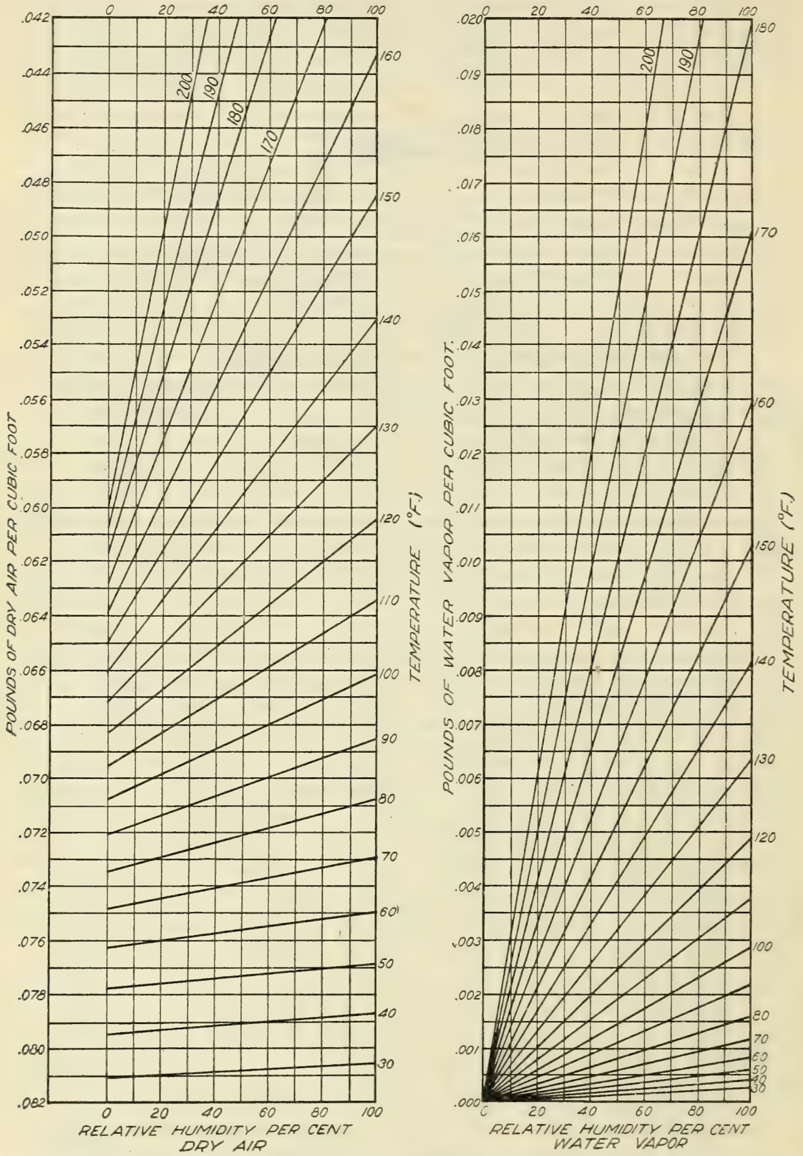

FIG. 8.—Pounds of dry air and of water vapor per cubic foot, at a barometer reading of 29.921 (based on Table 1, page 430, volume 1, Mechanical Equipment of Buildings, by L. A. Harding and A. C. Willard, 1917)

DETERMINATION OF AIR CONDITIONS

Figures 7, 8, and 9 will assist in solving recirculation problems. The curves in Figure 9 are vapor-pressure curves, graduated and expressed as pounds of water vapor per pound of dry air instead of

as vapor pressure. The curve corresponding to 0.020 pound of water vapor per pound of dry air, for example, represents a vapor pres-

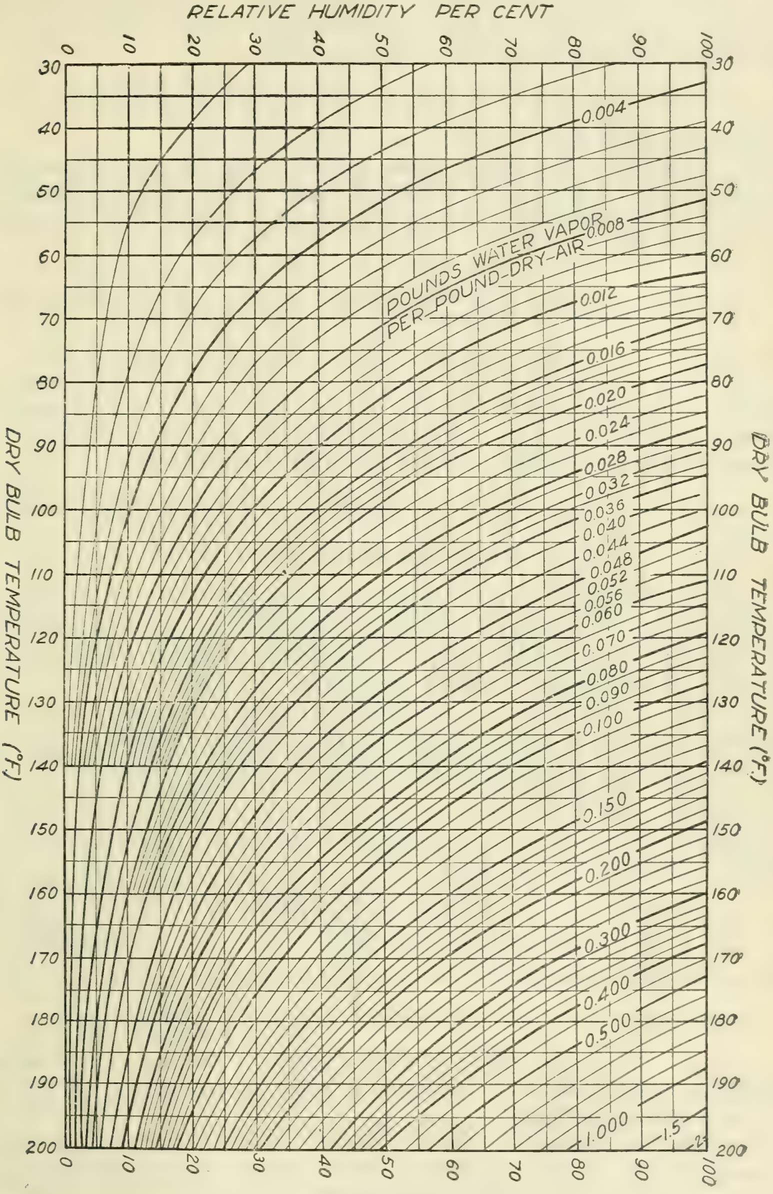

FIG. 9.—Pounds of water vapor per pound of dry air

sure of 0.93 inch of mercury. These curves, therefore, can be used as vapor pressure curves in problems which do not involve the actual computation of vapor pressures.

The practical application of the charts in solving various problems can best be illustrated by means of examples. The charts given here serve merely to indicate the methods of computation. In reaching exact results, the writers used larger charts than could be reproduced here, showing more subdivisions.

RELATIVE HUMIDITY FROM KNOWN WET AND DRY BULB READINGS

Example: Dry bulb = 150° F.; wet bulb = 100° F.

Find in figure 7 the intersection point of the lines corresponding to a dry bulb temperature of 150° F. and a wet bulb temperature of 100° F. The line representing the relative humidity at this point reads 18 per cent.

POUNDS OF DRY AIR AND OF WATER VAPOR PER CUBIC FOOT UNDER KNOWN CONDITIONS OF TEMPERATURE AND RELATIVE HUMIDITY

Example: Dry bulb = 150° F.; relative humidity = 18 per cent.

According to Figure 8, air at 150° F. and 18 per cent relative humidity contains 0.062 pound of dry air and 0.002 pound of water vapor per cubic foot. The weight of the mixture would then be the sum of these weights, or 0.064 pound per cubic foot.

CHANGE IN RELATIVE HUMIDITY PRODUCED BY A CHANGE IN TEMPERATURE

Example: Lowering the temperature from 150° F. and 18 per cent relative humidity to 100° F.

On Figure 9 start at the point corresponding to 150° F. and 18 per cent relative humidity and follow parallel to the nearest curve until the 100° F. dry bulb temperature line is reached. The relative humidity at this point reads 71 per cent.

Example: To find the temperature at which the air under the foregoing conditions would reach 100 per cent saturation.

Follow parallel to the nearest curve as before until the 100 per cent relative humidity line is reached. The temperature at this point reads 89° F.

Example: Raising the temperature from 70° F. and 50 per cent relative humidity to 150° F.

Find on Figure 9 the point corresponding to 70° F. and 50 per cent relative humidity and follow parallel to the nearest curve to the 150° F. dry bulb temperature line. The relative humidity at this point reads 5 per cent.

CHANGE IN VOLUME PRODUCED BY CHANGE IN TEMPERATURE

Example: One cubic foot of air at 150° F., 18 per cent relative humidity, would have at 100° F. a relative humidity of 71 per cent, according to Figure 9.

According to Figure 8, air at 150° F. and 18 per cent relative humidity contains 0.002 pound of water vapor and 0.062 pound of dry air, or 0.064 pound of the mixture per cubic foot, while at 100° F. and 71 per cent relative humidity the mixture contains 0.002 pound of water vapor and 0.068 pound of dry air and weighs 0.070 pound per cubic foot. Therefore the volume at 100° F. and 71 per cent relative humidity would be $\frac{0.064}{0.070}$, or 0.914 cubic foot.

WATER EVAPORATED DURING A GIVEN CHANGE OF TEMPERATURE AND HUMIDITY

Example: Air enters the drying chamber at 160° F. and 20 per cent relative humidity and leaves at 120° F. and 65 per cent relative humidity.

According to Figure 9, air at 160° F. and 20 per cent relative humidity contains 0.044 pound of water vapor per pound of dry air, while at 120° F. and 65 per cent relative humidity it contains 0.050 pound. Then there has been evaporated into the mixture $0.050-0.044$, or 0.006 pound of water vapor per pound of dry air. Since 1 cubic foot of the original mixture at 160° F. contained (fig. 8) 0.060 pound of dry air, there has been evaporated 0.060×0.006, or 0.00036 pound of water per cubic foot of the original mixture at 160° F. and 20 per cent relative humidity. If the air was entering the drying chamber at the rate of 1,000 cubic feet a minute, theoretically the evaporation would be 0.36 pound of water a minute.

ENGINEERING CALCULATIONS FOR DESIGNING A DRIER

The characteristics of a drier may be determined approximately by calculations based on the nature and quantities of the materials to be dried. When the drier is to be used for several materials separate computations must be made for each, so that the drier will fulfill the requirements for all. Such calculations are useful in designing a new drier and in remedying the defects of one already in operation.

To illustrate the computations involved, let it be assumed that a tunnel drier equipped for recirculation and employing the countercurrent system of air circulation is to be built with a capacity for drying 7 tons of fresh prunes daily. It will be assumed that the temperature of the outside air is 60° F. General experience in drying prunes indicates that if air is heated to 160° F., contains about 20 per cent relative humidity, and has a temperature drop of 35° F. in passing through the tunnel and a humidity at the discharge end not exceeding 60 to 65 per cent, the drying period will not exceed 25 hours and about 35 pounds of dried prunes will be obtained from 100 pounds of fresh prunes. The tunnel drier will be designed, therefore, to embody these characteristics.

SPREADING AREA

The following equation gives the spreading surface in square feet:

$$\frac{\text{Pounds fresh product dried per 24 hours} \times \text{drying time (hours)}}{\text{Pounds load per square foot} \times 24 \text{ hours}}$$

Assuming an average load of 3 pounds of fresh prunes per square foot of spreading surface, the spreading area will be $\frac{14{,}000 \times 25}{3 \times 24}$, or 4,861 square feet.

NUMBER OF CARS

If trays 3 feet square are used on trucks, each holding 2 stacks of trays 25 high, the spreading area per truck will be $3 \times 3 \times 2 \times 25$, or 450 square feet, and the nearest number of trucks furnishing 4,861 square feet of spreading surface will be 11, furnishing 4,950 square feet.

FREE CROSS-SECTIONAL AREA OF TUNNEL

If 3 inches of vertical space be allowed each tray, and 1 inch of this represents the thickness of the tray, there will be 2 inches of open vertical space per tray, or $\frac{2 \text{ inches} \times 36 \text{ inches} \times 2 \times 25}{144}$, which is 25 square feet of free cross-sectional area, through which the air can pass, provided all spaces on all sides of the trucks are occupied by baffles. This figure (25 square feet) will be used later in calculating the air velocities through the tunnel.

QUANTITY OF WATER EVAPORATED

If the tunnel is to have a capacity for drying 7 tons, or 14,000 pounds, of prunes each 24 hours, assuming that 35 pounds of the dried product will be obtained from every 100 pounds of the fresh fruit, there will be evaporated $14{,}000 \times 0.65$, or 9,100 pounds of water each 24 hours—an average of 6.32 pounds a minute. A definite amount of heat will be required to bring about the evaporation of this quantity of water.

HEAT REQUIREMENTS FOR EVAPORATION OF WATER

The requirement for sensible heat will be 1 B. t. u. per pound of water evaporated from the material per degree increase in its temperature. The actual temperatures of the products during drying lie above the wet bulb temperature and approach the dry bulb temperature as the drying progresses and the rate of evaporation decreases. For safety in calculation it may be assumed that the product becomes heated to the dry bulb temperature at the hot end of the tunnel. In the example considered, increasing the temperature of the fruit from 60° F. outside temperature to 160° F. in the tunnel makes the sensible heat requirement 100 B. t. u. per pound of water evaporated.

The latent heat of evaporation ranges from 1,035.6 B. t. u. at 100° F. to 977.8 B. t. u. at 200° F. per pound of water, but for ordinary purposes of calculation it may be considered as 1,000 B. t. u. per pound of water evaporated. The total heat of evaporation required per pound of water evaporated under the conditions assumed will be $100 + 1{,}000$, or 1,100 B. t. u., and for 6.32 pounds per minute it will be $6.32 \times 1{,}100$, or 6,952 B. t. u. per minute, on the average. The actual amount of heat which must be supplied by the fuel and carried by the air will be much larger to compensate for the heat losses in the drying system.

HEAT LOSSES

The principal ways in which heat is lost in a drying system without being used as heat of evaporation are (1) through incomplete combustion of the fuel, (2) in flue gases escaping from the stack, (3) by radiation through the walls of the system, (4) by air leakage through open seams or when doors are opened during drying operations, (5) through the removal of heated material, trays, and trucks from the drying chamber, and (6) through the necessary discharge of a portion of the air.

THERMAL EFFICIENCY

The relation between the amount of heat actually used in the evaporation of water in a drier and the total amount of heat generated by the fuel is called the thermal efficiency of the drying system. This ratio, which is expressed in percentage, is determined by dividing the number of heat units required for the total heat of evaporation by the number supplied by the fuel consumed during the same period and multiplying the result by 100. If 1,100 B. t. u. be taken as the average quantity of heat required to evaporate 1 pound of water, the thermal efficiency of the whole system can be expressed as follows:

$$\text{Thermal efficiency} = \frac{\text{Pounds water evaporated} \times 1{,}100 \text{ B. t. u.}}{\text{Units fuel used} \times \text{B. t. u. per unit}} \times 100.$$

The thermal efficiency of the system is the product of the thermal efficiencies of the heater and drying chamber calculated separately. The thermal efficiency of the heater shows the ratio between the heat generated by the fuel and the heat received from the fuel and carried by the air to the drying chamber. The thermal efficiency of the drying chamber gives the ratio between the heat received from the fuel and carried by the air and the total heat of evaporation.

Tunnel and cabinet driers operating under conditions of partial recirculation should average better than 40 to 50 per cent efficiency for the drying chamber. The thermal efficiency of the whole system will be influenced largely by the types of heaters (direct heat, direct radiation, and indirect radiation) which are selected for use in such driers. The thermal efficiencies of different heating systems in tunnel and cabinet driers shown in Table 5 may be assumed. These values may be used to determine the approximate amount of heat which must be generated and the portion of generated heat which must be carried by the air in the drier being designed. In each case the lower value given is sufficiently conservative to provide a reasonable margin of safety.

TABLE 5.—*Assumed thermal efficiencies of different heating systems*

Heating system	Thermal efficiency		
	Drying chamber (tunnel or cabinet)	Heater	Whole system
	Per cent	*Per cent*	*Per cent*
Direct heat	40–50	90–100	36–50
Direct radiation	40–50	80– 90	32–45
Indirect radiation	40–50	60– 70	24–35

HEAT TO BE GENERATED BY THE FUEL

If the heater selected is one of the direct radiation type, burning ordinary fuel oil, then, employing the data in Table 5, the thermal efficiency of the whole system may be expected to be at least 32 per cent. In other words, the total heat of evaporation will equal 32 per cent of the total heat which must be generated.

$$\frac{\text{Total heat of evaporation}}{0.32} = \text{Total heat which must be generated.}$$

For the drier in question this will be $\frac{6{,}952 \text{ B. t. u. per minute}}{0.32}$, or 21,725 B. t. u. per minute, on the average. One gallon of fuel oil yields 148,000 B. t. u. Therefore the burners must consume $\frac{21{,}725 \times 60}{148{,}000}$, or 9 gallons of fuel oil per hour.

AMOUNT OF GENERATED HEAT CARRIED BY THE AIR

Since the thermal efficiency of a heater of the direct radiation type, the one selected here, is assumed to be 80 per cent, the amount of generated heat carried by the air will be the total heat generated multiplied by 0.80, or 21,725 B. t. u. per minute × 0.80, which is equivalent to 17,380 B. t. u. per minute, on the average.

AMOUNT OF HEAT GIVEN UP BY THE AIR

Heat will be absorbed from the air to meet the requirements for total heat of evaporation, which has been estimated in this case to be 6,952 B. t. u. per minute. Heat will also be lost through radiation, air leakage, and absorption in heating the material, trays, and trucks. On this account an allowance of 10 per cent of the generated heat being carried by the air will be added—in this case, 17,380 × 0.10, or 1,738 B. t. u. per minute. The air in passing through the drying chamber will then be required to furnish, on the average, 6,952 + 1,738, or 8,690 B. t. u. per minute.

VOLUME OF AIR REQUIRED

The volume of air required to give up 8,690 B. t. u. of heat per minute is calculated from the specific heats of dry air and water vapor. Specific heat is the ratio between the heat required to raise (or, conversely, given off by cooling) a given weight of a substance 1 degree and that required to raise the same weight of water 1 degree, the specific heat of water being considered as 1.000. At constant pressure the specific heat of dry air is 0.2375, or approximately 0.24, while the specific heat of water vapor is 0.475. One cubic foot of a mixture of dry air and water vapor under given conditions of temperature and humidity will, in dropping 1° F., give up a number of B. t.u. represented by the expression: (Pounds of dry air per cubic foot × specific heat dry air) + (Pounds of water vapor per cubic foot × specific heat of water vapor). In dropping a given number of degrees Fahrenheit, the number of B. t. u. given up per cubic foot of mixture would be: Drop in degrees Fahrenheit × the foregoing expression. Consequently a given number of B. t. u. would be given up by the number of cubic feet of mixture represented by the fraction:

$$\frac{\text{Number of B. t. u. required}}{\text{Drop (°F.)} \times [\,(\text{Pounds of dry air per cubic foot} \times 0.24) + (\text{Pounds of water vapor per cubic foot} \times 0.475)\,]}$$

In the present problem, where an average of 8,690 B. t. u. per minute is required from air at 160° F. and 20 per cent relative humidity, dropping 35° F. in passing through the tunnel, and where the weights of dry air and of water vapor in the air at 160° F. and 20

per cent relative humidity (fig. 8) are 0.0598 and 0.0026, respectively, the air required, in cubic feet per minute, is as follows:

$$\frac{8{,}690}{35 \times [(0.0598 \times 0.24) + (0.0026 \times 0.475)]} = 16{,}000$$

VELOCITY OF AIR MOVEMENT

As previously estimated, the tunnel will have 25 square feet of free cross-sectional area. The velocity of movement of 16,000 cubic feet of air per minute through the tunnel therefore is $\frac{16{,}000}{25}$, or 640 feet per minute.

HUMIDITY AT AIR OUTLET END OF TUNNEL

The air entering the tunnel at 160° F. and 20 per cent relative humidity contains (fig. 8) 0.0598 pound of dry air and 0.0026 pound of water vapor per cubic foot. Into 16,000 cubic feet of this mixture is evaporated 6.32 pounds of water vapor. Thus, $\frac{6.32}{16{,}000}$, or 0.0004 pound of water vapor, would be associated with the weight of dry air and water vapor in 1 cubic foot of the original mixture. Disregarding the leakage of air into or out of the drying chamber, the air leaving the tunnel would contain 0.0026+0.0004, or 0.003 pound of water vapor, associated with 0.0598 pound of dry air, or $\frac{0.003}{0.0598}$, or 0.050 pound of water vapor per pound of dry air. Air at 125° F. containing 0.050 pound of water vapor per pound of dry air has 56 per cent relative humidity (fig. 9).

END POINT OF DEHYDRATION

Dehydrated fruits and vegetables should have a uniform moisture content low enough to inhibit undesirable microbic and chemical changes within the food and they should be free from any part of the life cycle of moths or other insects. The moisture content of dehydrated foods directly controls deterioration within the food, and the protection afforded by sulphuring or blanching will not prevent insufficiently dried products from soon becoming unfit for use. Dehydrated products having a low moisture content are not readily attacked by insects. In the long run the additional protection afforded by a low moisture content will more than make up to the producer the loss resulting from the longer drying time and greater weight shrinkage involved. To assure best keeping qualities the moisture content of fruits containing much sugar should not exceed 15 to 20 per cent, while that of other fruits and vegetables should not exceed 5 to 10 per cent, the preference in both cases being for the lower percentage.

The texture or "feel" of products is a guide in determining when the proper stage of dryness has been reached. At a given moisture content products usually feel softer when hot than after they have been cooled, and often they feel softer after standing until the moisture has become evenly distributed throughout the pieces than when first cooled.

A rough test for moisture in dried fruits is to take up a double handful, squeeze it tight into a ball, and release the pressure. If the

fruit seems soft, mushy, or wet, and sticks together when the pressure is released, the moisture content is probably 25 per cent or more. If the fruit is springy and when the pressure is released separates in a few seconds to form pieces of approximately the original size and shape, the moisture content is usually about 20 to 25 per cent. If the fruit feels hard or horny and does not press together, falling apart promptly when the pressure is released, the moisture content is probably below 20 per cent.

At the proper stage of dryness vegetables look thoroughly dry and are often hard or crisp.

The Association of Official Agricultural Chemists has published a water-oven method for the determination of moisture in dried apples and a vacuum-oven method for its determination in all dried fruits. Although the water-oven method gives accurate results only for apples, it gives relative results, valuable for factory control purposes, on other products. The vacuum-oven method gives sufficiently accurate results on all dried fruits and vegetables, but it requires more time and more expensive equipment than the other method.

In using either method care must be taken to select a composite sample from different portions of the lot, so that it will be representative of the lot as a whole. The sample is ground as fine as possible and kept in a sealed glass jar or tin can until used.

Water-oven method.—Weigh 5 to 10 grams of sample into a metal dish about 8.5 centimeters in diameter, provided with a cover, and break down all large lumps. Place the dish on the shelf, not the bottom, of an oven having a vent on top to afford ventilation. Dry for four hours at the temperature of boiling water, not lower than 96° C. Replace cover, cool in a desiccator, weigh, and compute the loss in weight as percentage of moisture.[1]

Vacuum-oven method.—Weigh 5 to 10 grams of sample into a metal dish about 8.5 centimeters in diameter, provided with a cover, and break down all large lumps. Dry in a vacuum oven at 70° C. for 12 hours at as low a pressure as possible, not to exceed 4 inches (100 millimeters) of mercury. During the drying, admit to the oven a slow current of air, about 2 bubbles a second, dried by bubbling through concentrated sulphuric acid. The metal dish must be placed in direct contact with the metal shelf of the oven. Replace cover, cool in a desiccator, weigh, and compute loss of weight as percentage of moisture. Disregard any temporary drop of oven temperature which may occur during the forepart of the drying period owing to rapid evaporation of water. With raisins and other fruit rich in sugar, use about 5 grams of sample and about 2 grams of finely divided asbestos dried with the dish. Moisten with hot water, mix sample and asbestos thoroughly, evaporate on the water bath barely to dryness, and complete drying.

CURING

Products are never uniformly dry when removed from the drier. Large pieces and pieces not as directly exposed to the currents of heated air as most of the material contain more moisture than the rest. The products should be stored in large bins until the moisture

[1] Dried peaches should be dried 4½ hours; apricots, 3½ hours; and pears, 5 hours.

becomes evenly distributed. This period of curing will usually take several weeks. An alternative method used in the Bureau of Chemistry is to place the dried product in large friction-top cans for curing, thus insuring complete protection from contamination and insect infestation.

Leafy vegetables, like spinach, must remain in the drier until the moisture content of the stems is very low. At this point the product is bulky and the leaves are brittle. For economy in packing and handling it is desirable to reduce the bulk by compression. For this purpose the leaves are exposed to currents of cool damp air until they have reabsorbed just enough moisture to make them slightly flexible.

INSECTS ATTACKING DRIED FRUITS [2]

From an economic standpoint the most serious type of spoilage after drying is due to insect infestation. Parker (*40*) [3] has studied the insect pests of dried fruits. The most serious insect pests, in the order of their importance, are the Indian-meal moth (*Plodia interpunctella* Hbn.), the saw-toothed grain beetle (*Silvanus surinamensis* L.), and the dried-fruit beetle (*Carpophilus hemipterus* L.). The Indian-meal moth and the saw-toothed grain beetle are primarily pests of grain, grain products, and nut meats, which, coupled with the fact that they are cosmopolitan in distribution, insures their general distribution not only in all kinds of establishments manufacturing and storing such commodities but also in retail stores and private homes. They are consequently present nearly everywhere, ready to infest dried fruits whenever the opportunity is presented. The Indian-meal moth is by far the most injurious because in the larval stage it spins much webbing, causing the fruit and the containers to become webbed and badly polluted with excrement. These are the outstanding evidences of infestation, which immediately catch the eye of a purchaser.

The insects which attack dried fruits pass through the usual insect life cycle. That is, the parent insect, whether it be a moth or a beetle, lays many eggs. From the eggs hatch the worms or grubs, which in turn ultimately pass into a chrysalis or pupal stage, from which the adults of the next generation emerge. In warm weather this life cycle, representing one generation, is passed in approximately one month. During colder weather the life cycle may be greatly prolonged, sometimes covering three or four months.

PREVENTIVE MEASURES

Even if the fruit is not directly attacked by insects it is important to prevent infestation, so that the product will not be polluted by webs and excreta. Preparation by lye dipping, sulphuring, or processing is supposed to kill all insect life in the fresh material. In the case of fruit packed in well-sealed containers, insect infestation practically always comes from eggs laid by adult insects on the product between the time it is removed from the drier and the

---

[2] Prepared by E. A. Back, Entomologist in Charge of Stored Product Insect Investigations, Bureau of Entomology.

[3] Italic numbers in parenthesis refer to the bibliography, p. 39.

time it is packed. If containers are not perfect, insects have little difficulty in gaining access to the contents. Therefore preventive measures must be directed toward absolute exclusion of all insect pests from products from the time they are removed from the drier, through handling, curing, and storing, until they are placed in insect-free, insect-proof containers.

Conveyors used to transfer products from the drier to the storage bins, as well as the storage bins, should be so constructed that they can be easily cleaned and steamed. The storage and packing room should be shut off from the rest of the plant, provided with every facility for the exclusion of insects, and adapted to fumigation by chemicals or heat. It should have no inaccessible corners or crevices where food materials might collect or insects breed unnoticed. No products, cartons, or other materials should be brought into the storage and packing room without having been treated by heat or other means to insure their freedom from live insects.

Products should be packed in the final containers or stored in insect-proof intermediate containers as soon as practicable after being dried. Products stored in bins for any length of time should be subjected to treatment with heat before being packed. If the products are being packed for immediate sale and if they have been stored with an unnecessarily low moisture content, this heat treatment may take the form of a short steam processing, which will kill all or nearly all live insect forms, and at the same time add a little water, thus making the product look fresher.

REMEDIAL MEASURES

Remedial measures should be applied whenever, in the opinion of the owner, the result warrants the cost. If prolonged storage is intended, the presence of a single insect is evidence that the insect problem should be watched closely. No treatment makes dried fruits immune to subsequent attack.

The two generally recognized methods of control are fumigation and treatment with heat. At present fumigation of the dried fruit itself is in disfavor with the dried-fruit industry in California because of the fire hazard if carbon disulphide is used and because of the possible danger of gas absorption if hydrocyanic-acid gas is used. This whole problem is now under investigation in the Bureau of Entomology. The three most commonly used fumigants are hydrocyanic-acid gas, carbon disulphide, and carbon tetrachloride.

HYDROCYANIC-ACID GAS

Hydrocyanic-acid gas, probably the most effective gas for fumigating dried-fruit establishments, packing rooms, etc., can not be depended upon for deep penetration. The fact, however, that it is lighter than air, nonexplosive, and noninflammable when used in ordinary fumigation work, and will not injure the texture or color of the fruit, or affect the machinery, woodwork, etc., is very much in its favor. Although dried fruits absorb this gas in varying quantities according to the method of packing, it is believed that the quantity absorbed does not affect the fruit as food for man (*34*). This subject is now under investigation.

Methods for generating hydrocyanic-acid gas and the precautions necessary in using it are discussed in Department of Agriculture

Bulletin 872 (*28*) and in Farmers' Bulletin 699 (*38*). The importance of killing insects in stemmer trash by hydrocyanic-acid gas is discussed by Hamlin and Benton (*35*). Hydrocyanic-acid gas is a most dangerous gas and should be used only by careful, thoroughly informed persons. One deep breath of the concentrated gas has been known to cause instant death.

CARBON DISULPHIDE

Carbon disulphide is an excellent fumigant for dried fruits whenever it can be used safely. The gas is explosive and inflammable in the presence of fire from any source, whether it be a lighted match, the spark caused by striking a nail, or the spark from an electric switch. It is used for fumigating under ordinary conditions and also in vacuum outfits. Because it is a gas heavier than air it can be depended upon for better penetration than hydrocyanic-acid gas, provided it is used in a tight container. Excellent results can not be obtained unless the material treated is fumigated in a very tight container. Because of its inflammable and explosive nature it is not recommended for the fumigation of large plants as single units. Information regarding carbon disulphide and its use as a fumigant is given in Farmers' Bulletin 799 (*36*).

CARBON TETRACHLORIDE

Carbon tetrachloride (*29*, *37*) upon evaporation forms a gas that is heavier than air. In this and in its power of penetration it resembles closely the gas of carbon disulphide. Stocks are fumigated with it in the same manner as when carbon disulphide is used. It has an advantage over carbon disulphide in that the gas is noninflammable and nonexplosive. In fact it is a standard fire extinguisher. It has, however, the great disadvantage of being about one-fourth to one-half as effective as carbon disulphide when equal quantities of the liquid of the two gases are used. It is also less reliable, in that results following its use are less dependable. As it costs about the same as carbon disulphide per pound, fumigation with it is more expensive than with carbon disulphide.

CONTROL BY HEAT

A dry heat ranging from 125° to 130° F., applied for several hours, will kill all insects attacking dried fruits, provided they are actually subjected to this temperature. Moist heat apparently is not so effective. No data bearing directly upon the use of heat in dried-fruit establishments were available in January, 1925. The subject of heat control is under investigation in the Bureau of Entomology. The installation of piping or other equipment sufficient to heat a plant to 125° to 130° F. is probably in the long run the cheapest and best method of controlling insects in the manufacturing plant itself. The value of heat for controlling insects in the fruit must be studied further before definite recommendations can be given.

PACKING AND STORING

For convenience in handling and to facilitate the application of heat or fumigation, products should be packed in the room where they were cured and stored. Such a room should be strictly clean,

dry, cool, and well ventilated (fig. 10). The doors should fit tight, and the windows should be covered with fine mesh screen to exclude dust and insects. An abundance of light assists in detecting the presence of insects and in keeping the room clean.

The types of containers chosen for packing will depend largely upon the severity of the storage conditions, with particular reference to the humidity and chances of insect infestation. An ideal container would be one which, while moderate in cost, would keep the product from absorbing moisture when exposed to the most severe conditions of storage and shipment and would be impervious to insects. Only sealed tin cans and glass jars give absolute protection against moisture absorption and insect infestation. Friction-top cans are nearly as good. Tin containers, necessary for export shipments of dehydrated foods, are more expensive than paper containers. Wooden boxes are generally used for bulk goods. "Liners" of heavy

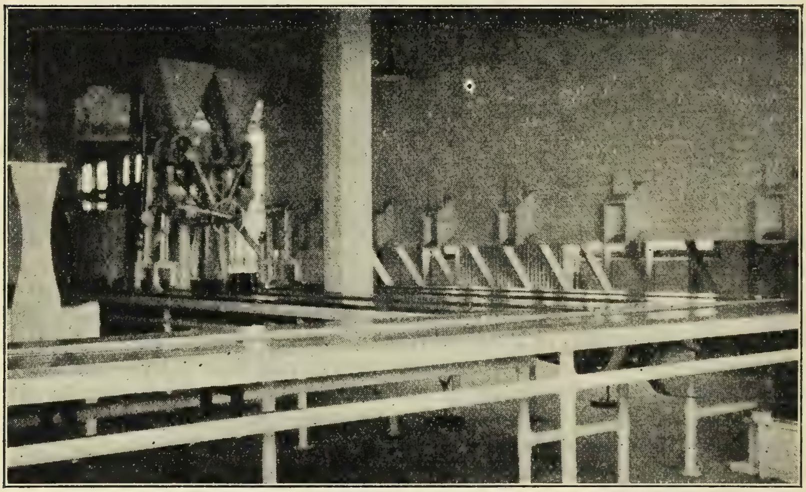

FIG. 10.—A packing room, with packing tables and conveyors, storage bins, and mixing and package, filling machinery

paper or cardboard, and sometimes additional liners of waxed paper, are used.

All types of paper containers with which experiments have been made allow the absorption of moisture when the products are stored in damp places. Also paper containers do not give perfect protection against all insects, some of which can bore holes in paper containers, while the larval forms of others are so small that they can crawl through the slightest imperfections at the joints where the cartons are sealed. Most products, however, keep satisfactorily in paper containers made of moisture-proof material and carefully sealed and preferably lined or wax wrapped, provided the initial moisture content is low and no live insects in any form enter the package.

The individual heavy paper cartons designed for fancy grades of food hold from a few ounces to a pound or more. The general styles are rectangular or cylindrical, both of which may be packed with or without "liners" and with or without waxed wrappers. Each

type has advantages and disadvantages. For example, the rectangular carton does not permit, with the same ease, as tight a seal as does the cylindrical carton, but it may be packed tighter and bought "knocked down." The cylindrical cartons will not pack as tight and are supplied to the packer "set up," thus requiring more storage space.

The use of paper containers permits the automatic assembling, lining, filling, weighing, sealing, labeling, and wrapping of packages. The economical use of machinery for these purposes depends, however, upon volume production. Makers of such machinery state that its employment is justified only when from 3,000 to 15,000 packages, all exactly alike, are handled daily. The product must be of a free-flowing character if automatic weighing machinery is to be used.

DETAILED DIRECTIONS FOR DRYING

Methods recommended for the preparation and drying of the principal fruits and vegetables, together with data on waste and yield, are given in Table 6. More detailed directions for this work are given in the following pages:

FRUITS

APPLES

Firm-flesh, late-maturing varieties are more suitable for dehydration than soft-flesh apples. The white-flesh varieties and those that bleach readily in the fumes of sulphur have a clean white appearance when dehydrated, which adds to their market value. Apples of the medium and lower grades are dried in years of normal production, but when large production causes low prices for the fresh fruit, better grades are used.

Apples should be mature but not overripe. The picking and handling should be done with great care in order to minimize bruising. Bruised spots become discolored and must be removed from the fruit when uniform color is desired.

The fruit is pared and cored by machine in one operation, trimmed by hand, cut into the desired form by machine, trayed, sulphured, and dried. As apple tissue discolors rapidly upon exposure to the air, the cut fruit is covered with cold water or weak saline solution between succeeding steps of the preparation. Apples are commonly dried in the form of ring slices, pie slices, or cubes.

APRICOTS

The most desirable flavor of the apricot is not developed until the fruit is fully ripe, but in this condition it is difficult to handle. Therefore, apricots should be dehydrated just before they become so soft that they are mashed or lose their shape during preparation and drying. At this time the color is nearly uniform throughout, and the slightly astringent flavor of the less mature fruit is absent.

Apricots are never peeled before drying. The remaining processes in their preparation and drying are similar to those for peaches.

TABLE 6.—*Details of dehydration of fruits and vegetables*

Product	Removal of inedible portions	Yield of fresh prepared from fresh unprepared	Subdivision to form for drying	Approximate tray load per square foot	Pretreatment: Type	Pretreatment: Time	Maximum drying temperatures	Average drying time	Dried product: Preferred moisture content	Dried product: Characteristics	Dried product: Keeping qualities [1]	Dried product: Yield: From fresh prepared	Dried product: Yield: From fresh unprepared
		Per cent		*Pounds*		*Minutes*	*°F.*	*Hours*	*Per cent*			*Per cent*	*Per cent*
FRUITS:													
Apples	Peel, core, trim	65–75	Cube or slice	1.5	Sulphur	15–30	140–160	6–10	10–15	Dry, springy	Good to fair	16–19	10–15
Apricots	Wash, halve, stone	90–94	Dried in halves	2.0	do	15–25	135–155	10–20	15–20	Dry, leathery	do	17–20	15–19
Bananas	Stem, peel	52–57	Dried whole or sliced.	1.0	do	15–30	140–160	10–20	15–20	Slightly moist to sticky, limber.	do	28–31	13–18
Cherries (unpitted).	Wash, stem	97–99	Dried whole	1.0	None or steam	0–2	135–160	8–12	15–20	do	Excellent	25–30	24–30
Cherries (sweet) (pitted).	do	77–83	do	1.0	do	0–2	135–160	8–12	15–20	do	do	24–28	18–24
Cranberries	do	100	Chop	.8	do	0–2	135–150	4–8	5–10	Dry, tough to brittle.	Excellent to good.	10–14	10–14
Figs	Wash [2]	100	Dried whole	3.0	Boiling lye dip [3]	1/12–1/2	135–160	10–20	15–20	Skin dry, glossy; flesh slightly moist.	Good	24–27	24–27
Grapes	Stem and seed after drying.	80–90	Subdivide clusters.	3.5	do [3]	1/12–1/2	150–180	20–30	15–20	do	Excellent to good.	26–30	21–27
Loganberries	Wash [2]	100	Dried whole	1.2	None		140–150	10–15	10–15	Dry but should not crumble.	do	15–18	15–18
Peaches	Halve, pit, peel	85–90	Dried in halves	2.5	Sulphur	15–30	145–155	15–24	15–20	Dry, leathery	Good to fair	17–21	14–19
Pears	Peel, halve, core	75–80	do	2.5	do	15–30	140–150	15–24	10–15	do	do	17–20	12–17
Prunes	Grade for size [2]	100	Dried whole	3.0	Boiling lye dip [3]	1/6–3/4	145–160	20–30	15–20	Skin dry; flesh slightly moist.	Excellent to good.	33–38	33–38
Raspberries (black).	Wash [2]	100	do	1.0	None		140–150	10–15	10–15	Dry but should not crumble.	Good	16–20	16–20
Rhubarb	Trim stalks, wash	55–60	Slice	1.0	Steam	2–4	140–150	10–15	5–10	Dry, tough	do	6–9	2–7
VEGETABLES:													
Beans (green)	Trim, wash	87–92	¾-inch lengths	.8	do	15–20	140–155	8–12	5–10	Dry, tough to brittle, greenish-black.	Excellent to good.	10–13	8–12
Cabbage	Trim	80–85	Slice or shred	1.0	do	2–6	140–150	8–12	5–7	Dry; ribs tough; leaves crisp.	Good to fair	8–12	6–10

Carrots	Wash, peel, trim	77–82	Cube, slice, or shred.	1.5	do	4–8	150–160	8–12	5–10	Dry, tough to brittle.	Excellent to good.	11–14	8–12
Celery	Trim, wash	77–82	Slice or shred	1.0	do	1–2	135–145	[4] 3–6; [5] 8–10	5–10	Dry; stalks tough; leaves crisp.	do	6–9	4–8
Corn	Husk, cut from cob after processing.	35–40	Kernels dried whole.	1.7	do	15–20	150–165	5–10	5–10	Dry, brittle	do	25–28	8–12
Onions	Trim	88–93	Slice or shred	1.2	do	½–1½	135–140	5–10	5–7	Dry, crisp	Good to fair	12–15	10–14
Parsnips	Wash, peel, trim	77–82	Cube, slice, or shred.	1.2	do	2–5	150–160	8–12	5–10	Dry, tough to brittle.	do	18–22	14–18
Peas (sugar)	Shell, clean, grade	55–60	Dried whole	1.0	Boiling water	1–2	140–150	8–12	5–10	Dry, hard, wrinkled.	Excellent to good.	18–22	9–14
Potatoes	Wash, peel, trim	78–82	Cube, slice, or shred.	1.2	Steam	5–7	145–155	8–12	5–10	Dry, brittle	do	22–25	17–21
Pumpkin	Wash, stem, cut open, seed	70–75	do	1.5	do	3–6	140–155	12–16	5–10	Dry, tough	do	7–9	4–8
Squash (Boston Marrow)	do	70–75	do	1.5	do	3–6	140–155	14–18	5–10	do	do	11–14	7–11
Spinach	Trim off roots, wash.	45–55	Leaves dried whole.	.5	do	2–5	140–150	6–10	5–7	Dry, crisp	Good to fair	7–11	3–6
Sweet potatoes	Wash, peel, trim	75–80	Slice	1.5	do	6–8	150–160	5–10	5–10	Dry, brittle	Excellent to good.	32–35	24–28
Tomatoes	Wash, trim,[2] peel	70–85	do	1.2	None or steam	0–3	140–150	10–14	5–8	do	Good to fair	5–8	3–7
Turnips	Wash, peel, trim	75–80	Cube, slice, or shred.	1.2	Steam	2–5	145–155	8–12	5–7	Dry, tough to brittle.	do	10–12	7–10

[1] Based on quality after storage for one year.
[2] Operation is optional.
[3] Use 1 to 3 per cent lye solution. After lye dipping, rinse fruit by momentary dip in fresh cold water.
[4] Leaves.
[5] Stalks.

BERRIES

Loganberries and red and black raspberries are handled in the same manner. When of market ripeness and firmness they are picked into shallow containers. As they crush easily, special precautions are necessary during all steps in their preparation and drying.

Berries are spread on drying trays and washed by light sprays of cold water, but they are not otherwise treated before drying. Only the conspicuously soft or crushed fruits that would mat and stick to the trays need be removed before drying. Pieces of stem, leaves, and undersized berries are readily removed by screening the dried product.

CHERRIES

Both sweet and sour cherries are dried. They are sorted to remove stems and imperfect fruits, thoroughly washed in tanks of cold running water, or by sprays of cold water, pitted by machine or left unpitted, trayed, steam processed, and dried. Unless it is collected and utilized in some way, much juice is lost in the pitting process.

CRANBERRIES

The ripe fruit is washed, fed into machines that cut or chop each berry into two or three parts, trayed, steam processed, and dried.

GRAPES

Most of the raisin grapes are sun-dried, unless drying by artificial heat is necessary to provide against losses resulting from early fall rains. A small part of the grape crop is dehydrated.

The unstemmed clusters or bunches of grapes are dipped into hot lye or soda solution, thoroughly rinsed in cold water, trayed, and dried.

Grapes stand high temperatures better than most other fruits. Temperatures up to 200° F. have been used for some varieties without visible injury to the fruit. The safer temperatures, however, are those given in Table 6.

If the grapes are to be marketed in clusters, they are removed from the drier when they contain 15 to 20 per cent of moisture. If they are to be stemmed, the moisture content should be reduced to 10 per cent or less, and the stemming begun as soon as the fruit has cooled. Under these conditions the grapes are hard, the stems are brittle and easy to remove, and the special stemming machines used in the process will not be gummed or clogged.

The seeding of grapes follows the stemming. Stemmed grapes are treated with steam or hot water, to increase their moisture content to about 20 per cent, and fed into seeding machines.

The stems of grapes constitute about 14 per cent by weight of fresh material before it has been prepared for drying. From 24 to 27 pounds of stemmed grapes, containing 10 per cent of moisture, are obtained from 100 pounds of fresh grapes, not including stems. If stemmed fruit containing 10 per cent of moisture is processed until it contains 20 per cent, the increase in weight will be about 12 pounds for every 100 pounds of the original product.

PEACHES

Yellow freestone peaches of the Muir and Lovell varieties are generally preferred, although the Elberta is dehydrated to a limited extent. The fruit should be firm, fully colored, and free from soft spots. The color of the fresh fruit should be uniform.

Peaches are graded for size and halved by cutting completely around the line of suture, and the pits are removed. The halved and pitted fruit may be peeled by any of the lye-peeling machines or left unpeeled. In either case the fruit is trayed, cup side up, in order to retain the juice that collects in the cavity, sulphured, and dried.

PEARS

The chief varieties of pears for drying are the Bartlett and the Anjou. The fruit is picked when the color is beginning to change from green to yellow and when, by merely being lifted, it is readily loosened from the branches. The pears are kept in boxes or crates under cool well-ventilated storage until firm ripe.

Pears are prepared in both the peeled and unpeeled forms. In preparing the peeled fruit the stem is pulled out, the calyx is cut off, and the peel is removed by hand or by lye dipping. The fruit is then halved and the core is removed by special scoops or knives. Between the operations in preparation the fruit should be kept in cold running water or cold weak saline solution to prevent darkening of the tissues. The prepared fruit is trayed, sulphured, and dried.

The degree of translucency in the dried product is controlled in the preparation by the extent of sulphuring. The time of sulphuring pears (Table 6) effectively preserves the original color and opaque condition of the fresh fruit.

PRUNES

The Agen (*Petite*) and Italian prunes are the varieties chiefly dried. Prunes should remain on the trees until they fall to the ground or until a light tapping of the branches causes them to fall. They are gathered from the orchard in shallow lug boxes holding not more than 60 pounds.

Prunes are prepared by cold-water washing, hot-lye dipping, rinsing, traying, and drying. The temperatures used for drying Italian prunes should not exceed 160° F.; Agen prunes are sometimes dried at 170° to 175° F. without visible injury.

VEGETABLES

BEANS (STRING AND STRINGLESS)

The terms "stringless" and "green" apply more particularly to the maturity than to the variety of beans. Many varieties are green or stringless at early maturity. In preparing string beans it is necessary to remove the ends and strings by hand, so that it is more economical to use stringless or green beans, which require less labor in trimming. The beans, culled free from tough, fibrous, or spotted material, are thoroughly washed, preferably by vigorous sprays of cold water. They are then cut across the short diameter of the pod by a special cutting machine, trayed, and steam processed. Blanching by immersion in hot water or in a very dilute (less than half an

ounce per gallon) solution of boiling soda gives good results. The soda intensifies and preserves the bright green color of the fresh material, but it must be dilute so that a noticeable flavor will not be imparted to the product.

CABBAGE

All dead, diseased, and discolored leaves are trimmed off, and the head is cut into quarters, usually by hand. If the cuts are made vertically through the central core, the segments of the stalk are easily cut out of the quarters. The quartered cabbage is sliced by means of a slaw cutter or other rotary slicer, after which it is trayed and steam processed until thoroughly heated, but not soggy or collapsed.

CARROTS

The best product is made from roots of medium size and stage of maturity. Large, very mature carrots furnish a more deeply colored product, but they are likely to have a coarse texture and strong flavor. Carrots are washed before peeling, or, if large quantities of fresh water are used, during the peeling process. They are peeled in machines of either the rotary abrasive or lye-peeling type and, after hand trimming, are sliced, cubed, or shredded. They are then trayed, steam processed, and dried.

CELERY

Celery is dehydrated chiefly for use in vegetable soup mixtures, for preparing celery soup, or for grinding to a powder to be used as seasoning. The same qualities of crisp freshness that are required for celery marketed in the fresh state are required in material for dehydration. All diseased and discolored parts are trimmed out by hand, and the trimmed celery is given a thorough washing. For soup mixtures it is finely shredded, leaves and all, and spread directly on the drying trays. For other purposes the leaves, which dry more rapidly, are trimmed from the thick fleshy stalks by hand and dried separately. The leaves are shredded or dried whole. The stalks, cut by a rotary slicer into transverse slices about one-half to three-quarters of an inch long, are spread on the drying trays and steam processed. The steaming must be short, so that the flavor and aroma will not be dissipated.

CORN (SWEET)

All of the varieties of corn which are suitable for table use make excellent dried products. Stowell's Evergreen is the preferred variety, because of its heavy yield and excellent table quality. Corn to be dried is in ideal condition for harvesting during the milk stage. It is husked either by hand or by power-driven husking machines. No special attempt need be made to remove the adhering silks, as they, together with the fine particles, can be readily blown out after the corn has been dried. The corn is blanched while still on the cob in order to set the milk before the kernels are removed. As young corn requires longer processing to set the milk, it is best to grade the material on the basis of maturity before processing. The proper stage of processing has been reached when no fluid escapes from the kernels when they are cut across. The corn is then drained and cut

from the cobs, either by hand slaw cutters or by power-driven corn-cutting machines, after which it is trayed and placed in the drier. Driers especially designed for drying sweet corn without using individual drying trays are in general use in the drying sections of Pennsylvania and Ohio (*19*). In driers using trays the maximum temperature of the air need not exceed 150° to 165° F., under which conditions the corn will be sufficiently dry in 5 to 10 hours. Temperatures as high as 170° can be used with safety if such temperatures prevail only during the first part of the drying. The freshly dried corn is fanned to remove all pieces of silk or cob or fine pieces of kernel.

ONIONS

The outer discolored layers are removed by hand, and the onions are sliced in a rotary slicer. After traying it is best to give them a light steaming, although they may be dried raw. Onions are especially susceptible to injury by heat, and should not be dried at temperatures above 140° F.

PARSNIPS

After being graded for size, parsnips are peeled and washed in a rotary abrasive peeler. Hand trimming, cutting, traying, and steam-processing complete their preparation for dehydration.

PEAS (GREEN OR SUGAR)

Peas are gathered when of full size but still green and tender and before the pods have begun to turn yellow. After vining, shelling, cleaning, and grading by machinery they are water-blanched, the processing being stopped before it splits the skins, and trayed for drying.

POTATOES

It is not profitable to use any grades of potatoes lower than No. 2, because of the great waste and extra labor in preparation. After being roughly graded for size they are peeled and washed in a rotary abrasive peeler. As potatoes darken rapidly in the air after the skins are removed, they are handled rapidly and kept covered with cold running water between the steps of preparation. They must be hand trimmed before being fed through the cutting machine. On leaving the cutters the pieces are covered with loose starch grains, which, if allowed to remain, will ruin the appearance of the product during drying and storage. The starch is most effectively removed immediately after cutting and traying by passing the loaded trays on a conveyor belt through a hood, in which they are copiously sprayed on both upper and lower sides by jets of cold water. This should be immediately followed by steam processing, which should be stopped when the pieces have been heated through to the centers but before they become mealy.

PUMPKIN AND SQUASH

Pumpkin and squash receive identical treatment. The firmer-fleshed, deep-colored varieties give a larger yield, with a more attractive color and fuller flavor. The necessity and difficulty of removing the skin make it impracticable to dehydrate such varieties as the

Hubbard. The gourds are stemmed, well washed to remove adhering dirt, and cut into large pieces by hand. The seeds, which contain oils that may become rancid during storage of the dehydrated product, as well as pith, must then be completely removed. For general purposes pumpkins are best cubed, although, if they are to be ultimately ground to flour, they may be sliced or shredded. To make the most attractive cubed product the skin should first be completely removed. This, of course, is unnecessary if the end product is to be flour. The steam processing should heat to the center and slightly soften the pieces, but if continued too long it will make the product undesirably sticky. Flour is made by grinding the dehydrated product.

SPINACH

Very young spinach does not dehydrate as well as that which is fairly well grown, but it should be harvested while still tender and crisp, not fibrous. The roots and coarse stems are cut from the leaves, and the inferior leaves are sorted out. Spinach requires thorough washing to entirely free it from dirt. The steam processing following traying should be stopped before the leaves begin to soften, collapse, and mat on the trays.

SWEET POTATOES

Although a very satisfactory product may be obtained, there is at present little active commercial production of dehydrated sweet potatoes, if any. Their lack of commercial development may be due to the fact that fresh sweet potatoes are commonly served on the table in whole or halved form, whereas it has not been customary to dehydrate them in pieces larger than half-inch slices. For drying they are peeled and washed in a rotary peeler, trimmed, sliced, trayed, and steam processed.

TOMATOES

Although dehydrated tomatoes have great possibilities for use in ketchups, purées, and soups, as well as in the stewed form, their commercial preparation has not been extensive. Only firm, fully-colored tomatoes should be used. The Stone is a satisfactory variety.

Tomatoes to be dried first receive a thorough washing with sprays of cold water. If they are to be used in the stewed form, they should be dipped in boiling water or subjected to jets of live steam for a few seconds to loosen the skin, chilled in cold water, and peeled by hand, when the stem cores are removed. If they are to be ground later, only the stem cores need be removed after washing. To slice the trimmed tomatoes for dehydration without excessively bruising and breaking them requires the use of a slicing machine with sharp and rapidly rotating knives. The tomatoes are then carefully trayed, one slice deep, and they may or may not be lightly steamed.

To insure satisfactory keeping qualities, the lack of which has been the principal reason for not producing them commercially, tomatoes must be dried to about 5 per cent moisture, when they will snap from the trays in whole slices if the trays are lightly tapped on the bottom. As the dried product is very hydroscopic, it must be packed immediately and stored in friction-top or sealed tin cans until wanted for immediate use. The slices must be brittle in order to be readily ground, and the ground product must be stored in tin to avoid caking.

TURNIPS

Turnips are prepared for dehydration by the methods and with the equipment used for carrots. They are sliced or cubed for general purposes, or they may be shredded for soup mixtures. They should be steam processed.

VEGETABLE SOUP MIXTURE

The individual vegetables making up soup mixtures are dried separately and mixed together in the proper proportions after drying. The formula may be varied somewhat, but potatoes usually comprise about 40 to 60 per cent of the mixture. Carrots, parsnips, turnips, and cabbage are mixed in moderate quantity with a little celery, onion, and spinach or parsley.

BIBLIOGRAPHY

DEHYDRATION OF FRUITS AND VEGETABLES

(1) Andrea, A. Louise. Dehydrating foods, fruits, vegetables, fish, and meats. Boston (1920). 206 pp.

(2) Banks, H. W. Commercial possibilities of dehydration. *In* Am. Food J. (1921), *16* (no. 4): 7–9; *16* (no. 5): 10–11.

(3) Caldwell, J. S. Evaporation of fruits. U. S. Dept. Agr. Bul. 1141 (1923). 64 pp.

(4) Carrier, W. H. The theory of atmospheric evaporation, with special reference to compartment dryers. *In* Ind. Eng. Chem. (1921), *13:* 432–438.

(5) ———— and Stacey, A. E., jr. The compartment dryer. *In* Ind. Eng. Chem. (1921), *13:* 438–447.

(6) Christie, A. W. Efficiency in dehydration. *In* Calif. Dept. Agr. Monthly Bul. (1921), *10:* 75–82.

(7) ————. Processing dehydrated prunes. *In* Western Canner and Packer (1922), *13* (no. 10): 38–39.

(8) ————. California dehydration statistics for 1922. *In* Western Canner and Packer (1923), *15* (no. 2): 26–27.

(9) ————. Dehydration statistics for California for 1922 and 1921. *In* Calif. Fruit News (1923), *68* (no. 1827): 7, 15.

(10) ———— and Ridley, G. B. Construction of farm dehydraters in California. *In* J. Am. Soc. Heat. Vent. Eng. (1923), *29:* 687–716.

(11) Cruess, W. V., and Christie, A. W. Dehydration of fruits. Calif. Agr. Exp. Sta. Bul. 330 (1921). 30 pp.

(12) ————. Some factors of dehydration efficiency. Calif. Agr. Exp. Sta. Bul. 337 (1921). 23 pp.

(13) Farnum, W. D. What is the matter with dehydration? *In* Am. Food J. (1921), *18:* 171–173.

(14) Gore, H. C., and Mangels, C. E. The relation of moisture content to the deterioration of raw-dried vegetables upon common storage. *In* Ind. Eng. Chem. (1921), *13:* 523–524.

(15) ———— and Rutledge, L. F. Control of the darkening of the dehydrated potato. *In* Chem. Age (1921), *29:* 457–458.

(16) Mangels, C. E., and Gore, H. C. Effect of heat on different dehydrated vegetables. *In* Ind. Eng. Chem. (1921), *13:* 525–526.

(17) Nichols, P. F. Sun-drying versus dehydration. *In* Calif. Dept. Agr. Monthly Bul. (1921), *10:* 191–199.

(18) ———— and Gross, C. R. Methods of preparing vegetables for dehydration—a study of different methods of treatment on the quality of potatoes, carrots and cabbage. *In* Chem. Age (1921), *29:* 139–141.

(19) Noel, W. A. Dehydration of sweet corn successful. *In* Am. Food J. (1922), *17:* 7–9.

(20) Powers, Ray. Prune drying in Oregon. *In* Calif. Dept. Agr. Monthly Bul. (1921), *10:* 316–323.

(21) Prescott, S. C. Some bacteriological aspects of dehydration. *In* J. Bact. (1920), *5:* 109–125.
(22) ——— and Sweet, L. D. Commercial dehydration: A factor in the solution of the international food problem. *In* Ann. Am. Acad. Pol. Soc. Sci. (1919), *83* (no. 172): 48–69.
(23) ——— Nichols, P. F., and Powers, Ray. Bacteria and molds in dehydrated vegetables. *In* Am. Food J. (1922), *17:* 11–16.
(24) Ridley, G. B. Tunnel dryers. *In* Ind. Eng. Chem. (1921), *13:* 453–60.
(25) Simons, S. C. Some essentials to success in dehydration. *In* Am. Food J. (1921), *16* (no. 9): 7–10.
(26) Swett, F. T. Relation of fruit by-products to horticulture. *In* Calif. Dept. Agr. Monthly Bul. (1921), *10:* 66–70.
(27) Wiegand, E. H., and Powers, Ray. Prune drying by recirculation. *In* Oregon Grower (1922), *3* (no. 10): 8–10.

CONTROL OF INSECT PESTS

(28) Back, E. A. Insect control in flour mills. U. S. Dept. Agr. Bul. 872 (1920). 40 pp.
(29) Chittenden, F. H., and Popenoe, C. H. Carbon tetrachlorid as a substitute for carbon bisulphid in fumigation against insects. U. S. Dept. Agr., Bur. Ent. Bul. 96, part 4 (1911). 5 pp.
(30) Dean, G. A. Heat as a means of controlling mill insects. *In* J. Econ. Entomol. (1911), *4:* 142–161.
(31) ———. Further data on heat as a means of controlling mill insects. *In* J. Econ. Entomol. (1913), *6:* 40–55.
(32) DeOng, E. R. Prevention and control of insects in dried fruits. *In* Calif. Dept. Agr. Monthly Bul. (1921), *10:* 72–74.
(33) Goodwin, W. H. Some factors affecting results in the use of high temperatures for the control of insects injuring cereal products. *In* J. Econ. Entomol. (1914), *7:* 313–322.
(34) Griffin, E. L., Neifert, I. E., Perrine, E., Duckett, A. B., and Back, E. A. Absorption and retention of hydrocyanic acid by fumigated food products. U. S. Dept. Agr. Bul. 1149 (1923), 16 pp.; U. S. Dept. Agr. Bul. 1307 (1924), 8 pp.
(35) Hamlin, J. C., and Benton, Curtis. Control of the saw-toothed grain beetle in raisins. *In* J. Econ. Entomol. (1925), *18.*
(36) Hinds, W. E. Carbon disulphide as an insecticide. U. S. Dept. Agr., Farmers' Bul. 799 (1917), 21 pp.
(37) Horne, W. T., Essig, E. O., and Hermes, W. B. Plant disease and pest control. *In* Calif. Agr. Exp. Sta. Cir. 265 (1923), p. 94.
(38) Howard, L. O., and Popenoe, C. H. Hydrocyanic-acid gas against household insects. U. S. Dept. Agr. Farmers' Bul. 699 (1916), 8 pp.
(39) Neifert, I. E., Cook, F. C., Roark, R. C., Tonkin, W. H., Back, E. A., and Cotton, R. T. Fumigation against grain weevils with various volatile organic compounds. U. S. Dept. Agr. Bul. 1313 (1925). 43 pp.
(40) Parker, W. B. Control of dried-fruit insects in California. U. S. Dept. Agr. Bul. 235 (1915). 15 pp.

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY
▽

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

August 27, 1925

Secretary of Agriculture	W. M. JARDINE.
Assistant Secretary	R. W. DUNLAP.
Director of Scientific Work	———
Director of Regulatory Work	WALTER G. CAMPBELL.
Director of Extension Work	C. W. WARBURTON.
Director of Information	NELSON ANTRIM CRAWFORD.
Director of Personnel and Business Administration	W. W. STOCKBERGER.
Solicitor	R. W. WILLIAMS.
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Agricultural Economics	HENRY C. TAYLOR, *Chief.*
Bureau of Animal Industry	———, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	W. B. GREELEY, *Chief.*
Bureau of Chemistry	C. A. BROWNE, *Chief.*
Bureau of Soils	MILTON WHITNEY, *Chief.*
Bureau of Entomology	L. O. HOWARD, *Chief.*
Bureau of Biological Survey	E. W. NELSON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Bureau of Dairying	C. W. LARSON, *Chief.*
Fixed Nitrogen Research Laboratory	F. G. COTTRELL, *Director.*
Office of Experiment Stations	E. W. ALLEN, *Chief.*
Office of Cooperative Extension Work	C. B. SMITH, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*
Federal Horticultural Board	C. L. MARLATT, *Chairman.*
Insecticide and Fungicide Board	J. K. HAYWOOD, *Chairman.*
Packers and Stockyards Administration	JOHN T. CAINE, *in Charge.*
Grain Futures Administration	J. W. T. DUVEL, *Acting in Charge.*

This bulletin is a contribution from

Bureau of Chemistry	C. A. BROWNE, *Chief.*
Laboratory of Fruit and Vegetable Chemistry	E. M. CHACE, *in Charge.*
Office of Development Work	D. J. PRICE, *in Charge.*